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PROGRESS IN STUDY OF NORMAL AND ABNORMAL STEEL

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Abstract

The meaning of the terms, normal and abnormal steel, is defined and the characteristics of the normal and abnormal structure in carburizing steel and tool steel are illustrated. It is shown that under certain quenching conditions abnormal steel is more prone to give soft spots than normal steel, but that with drastic quenching in brine or in a sodium hydroxide solution, it is possible to completely prevent the formation of soft spots in both normal and abnormal steel. It is shown that normality and abnormality have their origin in the deoxidation procedure of steel making and that in particular additions of aluminum and ferrovanadium in the mold produced abnormality.

I. INTRODUCTION

SINCE the work of McQuaid and Elm[1] the terms "abnormal" and "normal" steel have become fairly familiar to steel treaters. Many are still skeptical over the view that a carburized steel

[1]E. W. Ehn, Influence of dissolved oxide on the carburizing and hardening qualities of steel. *Journal*, Iron and Steel Institute, 1922, No. 1, Vol. CV, p. 157.
W. H. McQuaid and E. W. Ehn, Effect of quality of steel on case-carburizing results. TRANSACTIONS American Institute of Mining and Metallurgical Engineers, Vol. LXVII, 1922, p. 341.
E. W. Ehn, Irregularities in case-hardening work caused by improperly made steel. TRANSACTIONS American Society for Steel Treating, September (1922), Vol. 2, p. 1177.
E. W. Ehn, Causes of failures in case-hardening steel. *Iron Age*, Vol. 109, 1922, p. 1807.

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with an abnormal structure will not harden so readily and uniformly as a steel with a normal structure, but on the other hand the McQuaid-Ehn carburizing test is being used constantly in many steel mills and by carburizers as a check on the suitability of the steel for case-hardening[2]. The test is also coming into vogue as a supplement to the other metallographic methods—if only to satisfy the investigators' curiosity. Recently, Weber[3] in a study of electric welding, made carburizing tests of welds fused under different atmospheres, variations being noted in the structures of the carburized layers according to the welding atmosphere used. The quite general application of the test has also helped to emphasize the fact that considerable differences may exist in the carburizing rates of different steels. One of the largest steel companies is advertising a special carburizing steel differing from the regular S. A. E. 1020 grade in having a high manganese content combined with a high sulphur content, the steel being stated to carburize faster than S. A. E. 1020.

The explanation for abnormal steel given by Ehn was that abnormality is caused by dissolved oxides or submicroscopic particles of oxides. Perhaps because of a certain indefiniteness about this explanation, or because of the controversial nature of some of the discussion of the subject, or simply because of its newness, our conception and knowledge of abnormal steel remains rather hazy. The Bureau of Standards has been making an investigation of the subject. Although the investigation is not completed as yet, the more concrete results obtained thus far are reported in this paper, theoretical speculations being as far as possible avoided at this stage.

The authors take pleasure in acknowledging the hearty cooperation of the many metallurgists and steel companies who generously provided samples for the investigation, and who also gaves their advice and freely divulged the results of their experience on this problem, making the study a truly co-operative one between the Bureau and the industry. The suggestions of Dr. H. W. Gillett, Chief, Division of Metallurgy, have aided materi-

[2]W. G. Hildorf, Improvements in automotive steels. *Iron Age*, Vol. 116, 1925, p. 1378, p. 1447.

J. Bethune and W. G. Hildorf, Gear steels and the production of automobile gears. *Journal* Society of Automotive Engineers, Vol. 19, 1926, p. 422.

[3]L. J. Weber, Studies on electric welding, Preprint of paper before American Society for Steel Treating Convention, Chicago, September 1926.

ally in the investigation. Acknowledgement is also due C. A. Raub and D. Aronowsky for the metallographic work.

II. Characteristics of the Normal and Abnormal Structure

Laying aside for the moment the question whether or not abnormal steel is more liable to show soft spots, one can hardly dispute from Ehn's work that there is a difference in structure between steels, which becomes readily apparent only after carburizing. On the basis of these structural differences, the steel is classed as "normal" or "abnormal". In the McQuaid-Ehn test, the sample is carburized at about 1725 degrees Fahr. (940 degrees Cent.) until a thick carburized layer is obtained, with a well-defined hypereutectoid zone, and is then slowly cooled. Upon examination under the microscope, differences between normal and abnormal steel can be noted in the structures of the core, transition zone, and hypereutectoid zone. The last is usually the most characteristic. In abnormal steel the grain is finer and the cementite of the hypereutectoid zone is coalesced into thick masses generally surrounded by ferrite. In normal steel the grain is coarser, and in the hypereutectoid zone there are large grains of pearlite bounded by thin films of cementite. The chief mark of the abnormal structure is the lack of perfection of the pearlite crystallization in the hypereutectoid zone, as evidenced by the coalescence of the cementite and its separation from the ferrite. The carburized layer in an abnormal steel is usually considerably thinner than in a normal steel. Fig. 1 shows the carburized layers of a typical normal and abnormal steel.

Fig. 1 illustrates the extremes of normality and abnormality in commercial carbon carburizing steel. The differences between the two types are not always so marked, however, there being intermediate gradations, and it is often doubtful how to classify a steel according to the McQuaid-Ehn test. Some of the steel companies have drawn up charts showing micrographs of steels of different grain size, with as many as ten grades according to the grain size. It might appear that this method of classification does not give sufficient weight to the factor of coalescence of the cementite. In plain carbon steel, fineness of grain is usually associated with coalescence of the cementite. With alloy carburizing steels, which are widely used, this is not always so, and a very

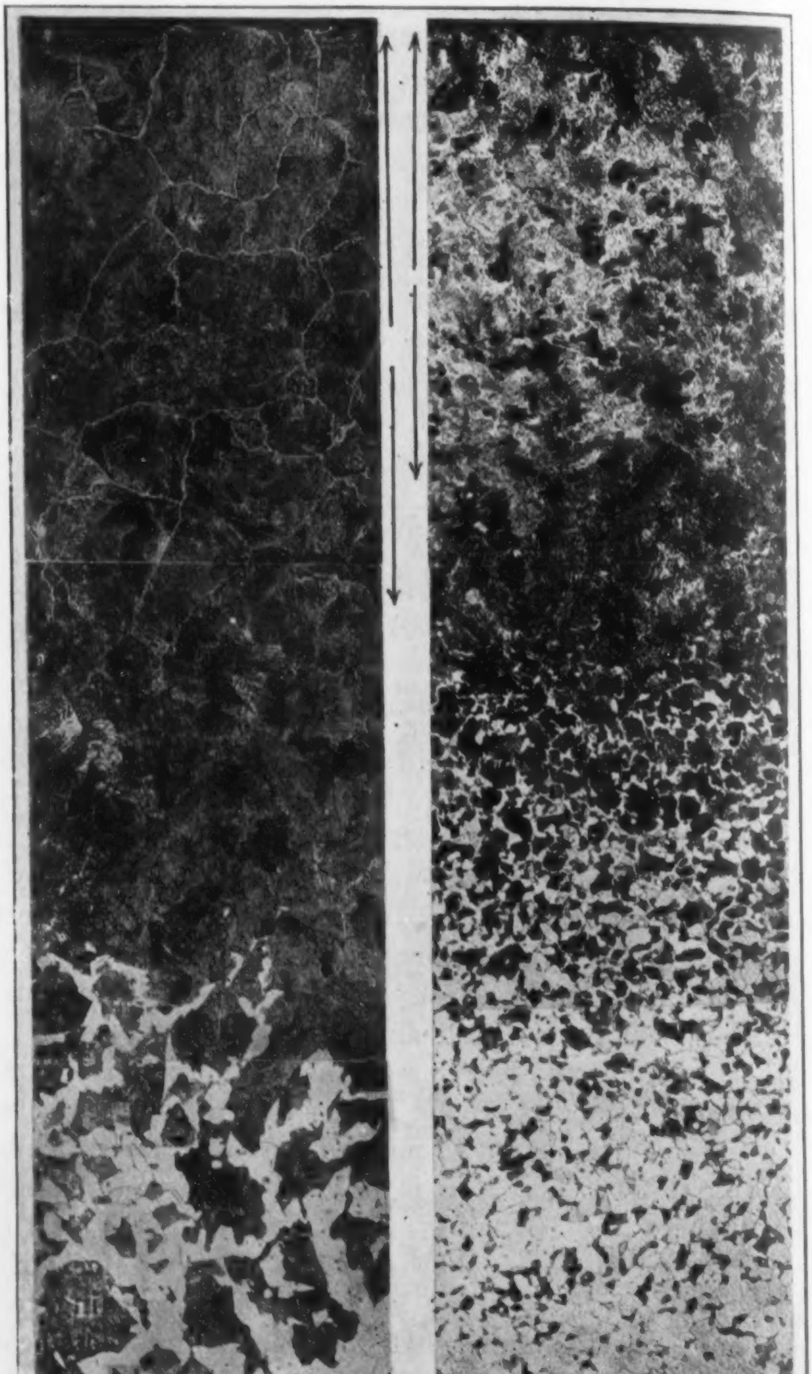


Fig. 1a—(Note. In All of the Micrographs, Unless Otherwise Indicated, the Etching Reagent was 2 per cent Nitric Acid in Alcohol. The Letters, N and A, Refer to Normal and Abnormal, Respectively.)

The Carburized Layers of Normal and Abnormal Carburizing Steel. The Abnormal Steel has a Finer Grain, a Shallower Case, and Shows Coalescence of the Cementite in the Hypereutectoid Zone. The Arrows Indicate the Extent of the Hypereutectoid Zone. 100 x.

fine grained steel may show only slight coalescence of the cementite. Fig. 2 shows the structure of the carburized layer of a chromium-vanadium steel (C, 0.50 per cent; Mn, 0.80 per cent; Cr, 0.25 per cent; V, 0.18 per cent) with extremely fine grain, but with only slight coalescence of the cementite.

A question which comes up in classifying a steel by this test is the effect of the previous condition or treatment of the steel—whether it is cast, hot-worked, annealed, etc. A few experiments at the Bureau of Standards[4] have indicated that the previous condition of the steel generally has little effect on the structure of the carburized layer. A 2-inch round rolled from a 21x21 inch normal steel ingot had the same normal structure as the ingot. A bar cold-rolled to $\frac{1}{2}$ inch flat from a $1\frac{1}{2}$-inch round normal bar, had the same normal structure as the original bar. Simple annealing prior to carburizing had no effect. A bar cold-rolled to a $\frac{3}{16}$-inch flat from a 1-inch abnormal steel bar had the same abnormal structure as the original bar. Annealing this cold-rolled bar prior to carburizing had no effect.

The Bureau of Mines[5], however, which has also been investigating the problem of normal and abnormal steel, has reported that in some instances, heating what appeared to be an abnormal steel to about 1600 degrees Fahr. (870 degrees Cent.) for 20 minutes and cooling in air resulted in a more normal structure on subsequent carburizing. It was also stated that some steels which were not transformed to a more normal structure by a single heating and cooling, approached nearer to a normal structure after repeated heatings and coolings. The more pronounced abnormal steels, however, were scarcely affected by as many as ten repeated treatments. Fig. 3 shows the structure of a steel changed to a more normal structure by three repeated treatments and another not affected by these treatments.

As a matter of classification, therefore, the fact that one steel may be made normal or more nearly so by heat treatment, while another may not be affected, might perhaps be taken into consideration. The process by which the transformation is brought about is of theoretical interest, since it should throw some light on the

[4] S. Epstein, Discussion of W. J. Merten:—Irregular carburization of iron and iron alloys—the cause and prevention. TRANSACTIONS American Society for Steel Treating, Vol. IX, June 1926, p. 920.

[5] R. B. Norton, Thesis on Abnormal Steel. Carnegie Institute of Technology.

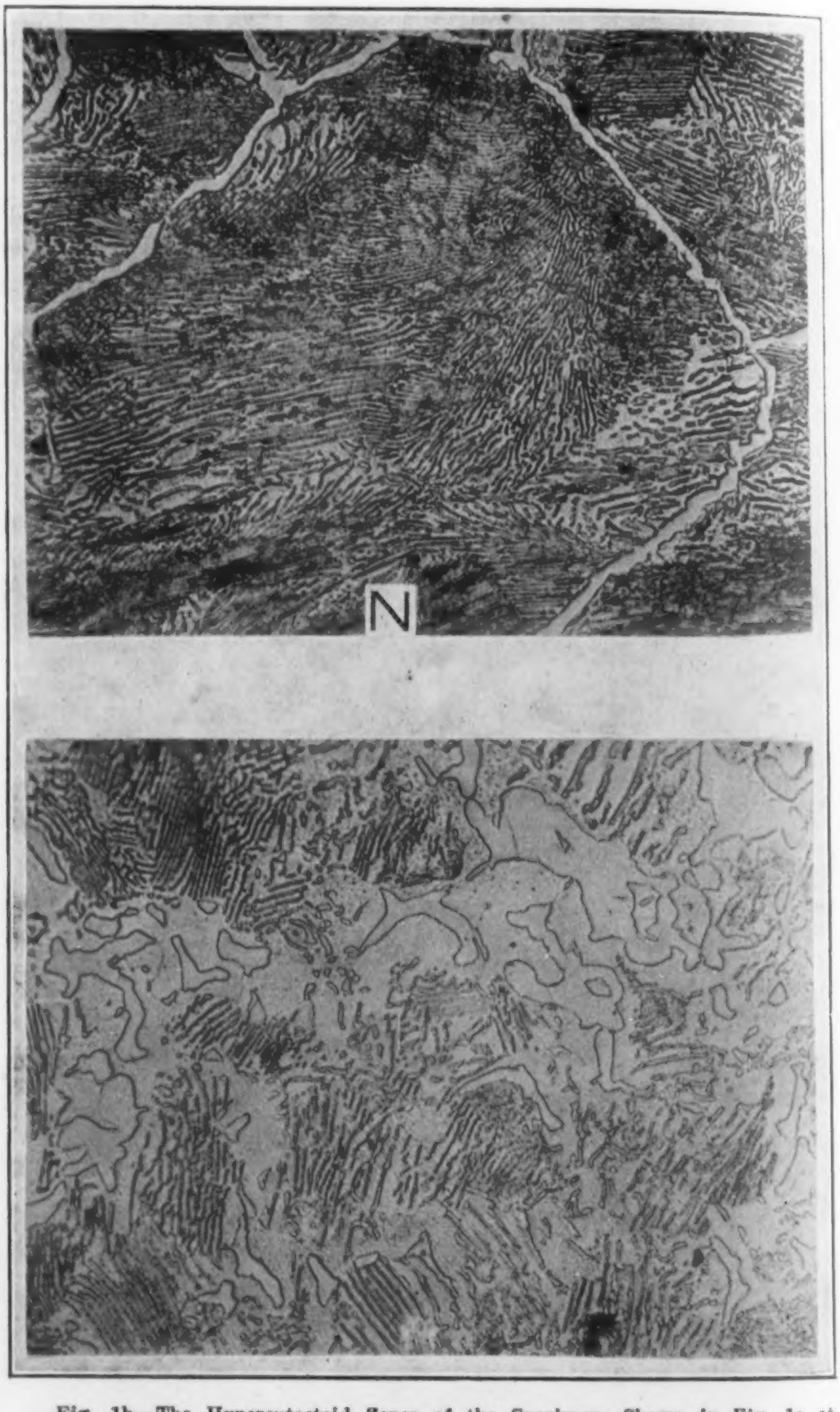


Fig. 1b—The Hypereutectoid Zones of the Specimens Shown in Fig. 1a at Higher Magnification. The Coalescence of the Cementite and Its Separation from the Ferrite in the Abnormal Steel are Very Marked. In the Normal Steel, the Pearlite Grains are Large and Well Developed, Surrounded by Thin Cementite Envelopes. 500 x.

cause of abnormality. As a means, however, of changing abnormal steel to normal the heat treatment method appears to be impracticable since not all steels are affected and most steels would require repeated treatments, which is not commercially feasible.

It has been observed that there may be "segregations of abnormality." Fig. 4 shows the cross-section of a bar of efferves-

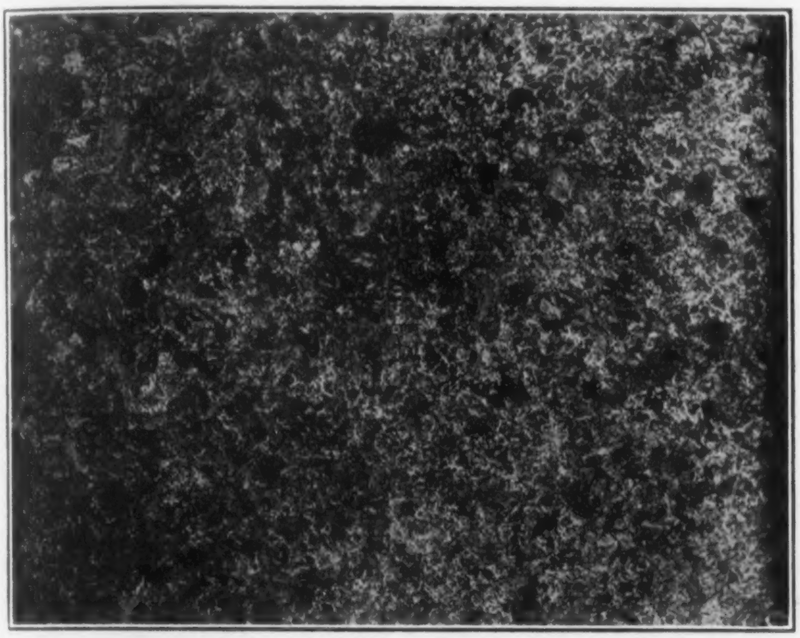


Fig. 2—The Carburized Layer of a Chromium-vanadium Steel. The Grain is Very Fine, but there is no Pronounced Coalescence of the Cementite. 100 x.

cent steel; the inner segregate is abnormal, whereas the outer zone is normal. For a complete McQuaid test of a given steel, it is necessary, therefore, to inspect a full cross-section of a bar or different portions of an ingot.

III. Significance of Normal and Abnormal Structures

As has been indicated, the extreme type of normal steel with very large grain is not always the desideratum of metallurgists who specify this test, for the obvious reason that a coarse grain makes for brittleness. A more intermediate grade with a finer grain may be preferred. Those who are not concerned particularly over soft spots or who experience no difficulties from them may specify the finest grain possible. Users of the fine-grained

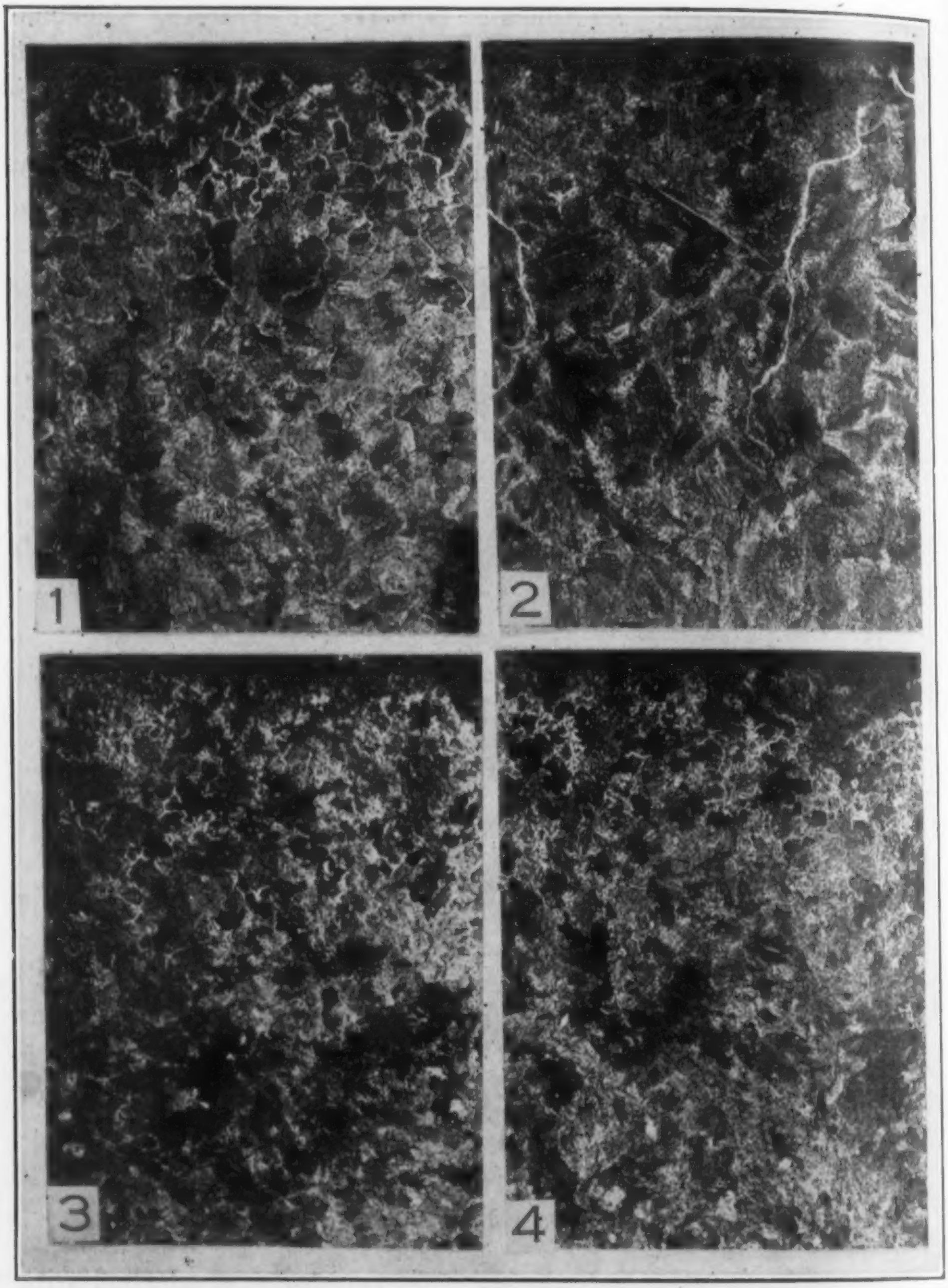


Fig. 3—Nos 1 and 2. The Carburized Layers of a Carburizing Steel Before and After Three Repeated Heatings at 870 degrees Cent. for 20 Minutes and Cooling in Air. It can be Seen that the Heat Treatments Produced a Change Toward a More Normal Carburized Structure. Nos. 3 and 4. The Carburized Layers of an Abnormal Steel Before and After Three Repeated Heatings at 870 degrees Cent. for 20 Minutes and Cooling in Air. The Heat Treatments had no Effect on the Carburized Structure. 100 x.

alloy steels showing only slight coalescence of the cementite—a nickel-molybdenum steel for roller bearings, for example,—state

they have no trouble from soft spots with this grade of steel. On the other hand, when speed of carburization is sought, the metallurgist may specify a coarse-grained steel not primarily because he wishes to avoid soft spots, but because a coarse-grained steel will generally carburize faster; the increase in the carburizing rate may amount to about 15 per cent so that commercially it is not a negligible factor.

Of course, the import of the above is that the terms normal and abnormal, should not be taken as synonymous with "good" and

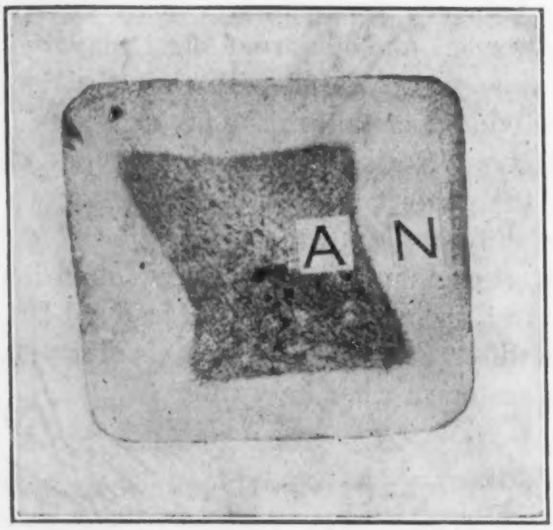


Fig. 4—A Cross-section of a Bar Deeply Etched with Hot 1:1 Hydrochloric Acid. The Carburized Structure of the Inner Segregate was Abnormal; the Outer Zone was Normal. Natural Size.

"bad". By normal steel is meant simply a steel with a certain carburizing structure as opposed to an abnormal steel with a somewhat different carburizing structure. It will be shown below that for the extremes of these two grades, an abnormal steel is more prone to give soft spots than a normal steel. This does not condemn abnormal steel or commend normal steel for every or any purpose. No work has been done, for instance, to show that abnormal steel has inferior mechanical properties to normal steel. On the contrary, as was indicated above, it may be presumed from the fine grain of abnormal steel that it is perhaps superior in this respect. It is not claimed to be impossible to satisfactorily harden

abnormal steel; in fact, it has already been shown[6] and will be brought out in this paper that with due precautions and expedients abnormal steel can be case-hardened uniformly without soft spots. The metallurgist must decide, however, whether these expedients will serve or are feasible in his own plant, or whether he would rather secure a normal steel.

It is unfortunate that the terms, normal and abnormal, with their connotations of "good" and "bad" have gained precedence in describing these steels, and it would be well if more suitable terms were found and adopted. Alloy steels have taught the steel treater that each type of steel has its particular field and advantages. Normal and abnormal steel may be looked at somewhat in the same way. Faced with the special conditions in his plant each individual metallurgist may find reasons which to him are sufficient, for favoring one of these types of steel over the other. With the subject still in its early stages it is perhaps as well that the different grades are being tried out by the users. Some of the steel companies have already found it possible to some extent to control their steel by the McQuaid-Ehn test, and are supplying the different gradations and classifications on the policy of giving the customer what he wants.

IV. Quenching Tests and Hardness Measurements of Normal and Abnormal Steel

In the operations of case-hardening, there are so many possible irregularities which may cause soft spots, that the first reaction to Ehn's claim that in his work soft spots were to be attributed to the steel, was to seek the cause rather in some shortcoming in the carburizing or quenching, or as Dr. Hadfield[7] stated it, "indifferent hardening". The whole question of normal and abnormal steel turns largely about this point, and it was the first aim of the Bureau's investigation to show whether abnormal steel is more prone to give soft spots than normal steel. The method used was

[6] W. J. Merten, Fused salt baths for the prevention of soft spots in quenched high carbon and carburized steels. TRANSACTIONS American Society for Steel Treating, Vol. VII, January 1925, p. 28.

W. J. Merten, Irregular carburization of iron and iron alloys,—the cause and prevention. TRANSACTIONS American Society for Steel Treating, Vol. IX, June 1926, p. 907.

[7] Dr. W. H. Hatfield, Discussion of E. W. Ehn:—Influence of dissolved oxide on the carburizing and hardening qualities of steel. *Journal* Iron and Steel Institute, 1922, No. 1, Vol. CV, page 198.

to quench carburized samples of normal and abnormal steel of the same size, similarly treated *in pairs,* and to make Rockwell hardness surveys of the surfaces.

Before giving the results of these tests an interesting observation in regard to the effect of dissolved gas in the water used for quenching, will be described. This behavior of dissolved gas applies to the quenching of steel in general, and not alone to the problem of abnormal steel. In an early series of tests, the specimens were heated, prior to quenching, in the usual type of electric muffle furnace which, of course, is not air tight. More soft spots appeared in the abnormal than normal samples, but the objection was raised to these results that with access to air there is considerable scaling of the specimens and that this scaling may have been primarily responsible for the soft spots. Heating in a salt bath containing some cyanide to obviate scaling eliminated the soft spots on *brine quenching;* but in repeated tests, soft spots were invariably formed in *water quenching* from the cyanide salt bath.

The soft spots were found to be associated with blue and brown discolorations of the surfaces. The discolorations appeared to be formed while the specimens were in the water and were finally traced to the presence of dissolved air in the tap water used. When the water was boiled to expel the dissolved gas, the discolorations became much less marked, and there was a decrease in the number of soft spots. When oxygen was bubbled through the boiled water, the discolored areas reappeared, accompanied by an increase of soft spots on specimens quenched in such water. When carbon dioxide gas, which is extremely soluble in water, was bubbled through (in every case, of course, previous to and not simultaneously with the quenching) the discolored areas were not marked, since the carbon dioxide did not oxidize the steel, but practically the entire surfaces of the specimens were soft.

On quenching in 10 per cent brine and saturated brine solutions and in a 5 per cent sodium hydroxide solution, the surfaces were not discolored and there were no soft spots in either the normal or abnormal specimens. This is in agreement with the work of Merten cited previously.

Figs. 5, 6, 7, and 8 show photographs, about half natural size, of the appearance of the four side surfaces of the blocks

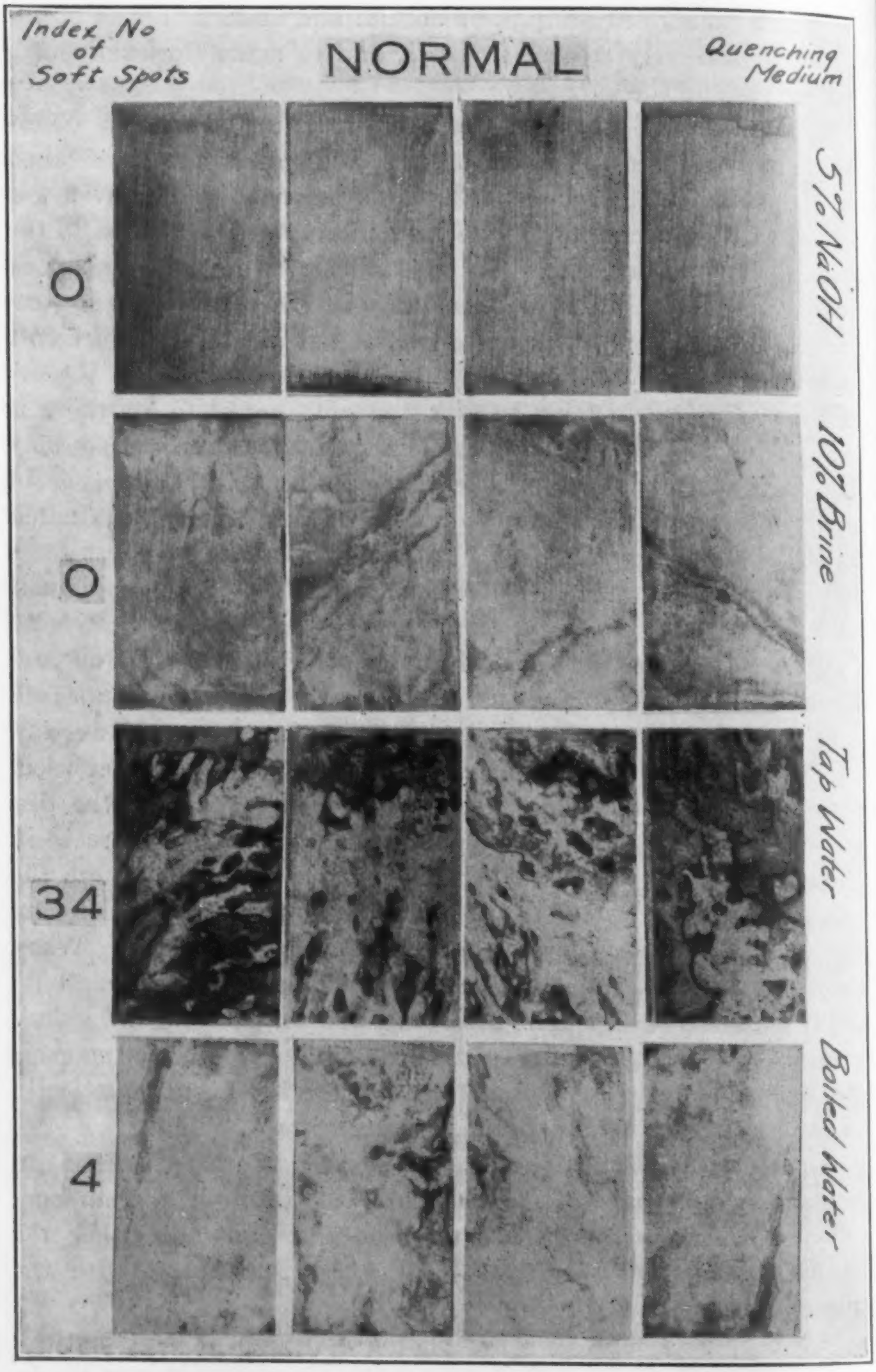
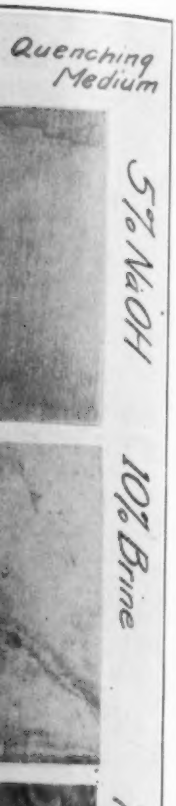


Fig. 5—Appearance of the Surfaces of the Four Side Faces of Blocks of Normal and Abnormal Steel Heated in a Cyanide Salt Bath and Quenched in the Coolants Indicated. The Relation is Shown Between the Discolorations on the Surfaces and the Number of Soft Spots. About ½ Natural Size.



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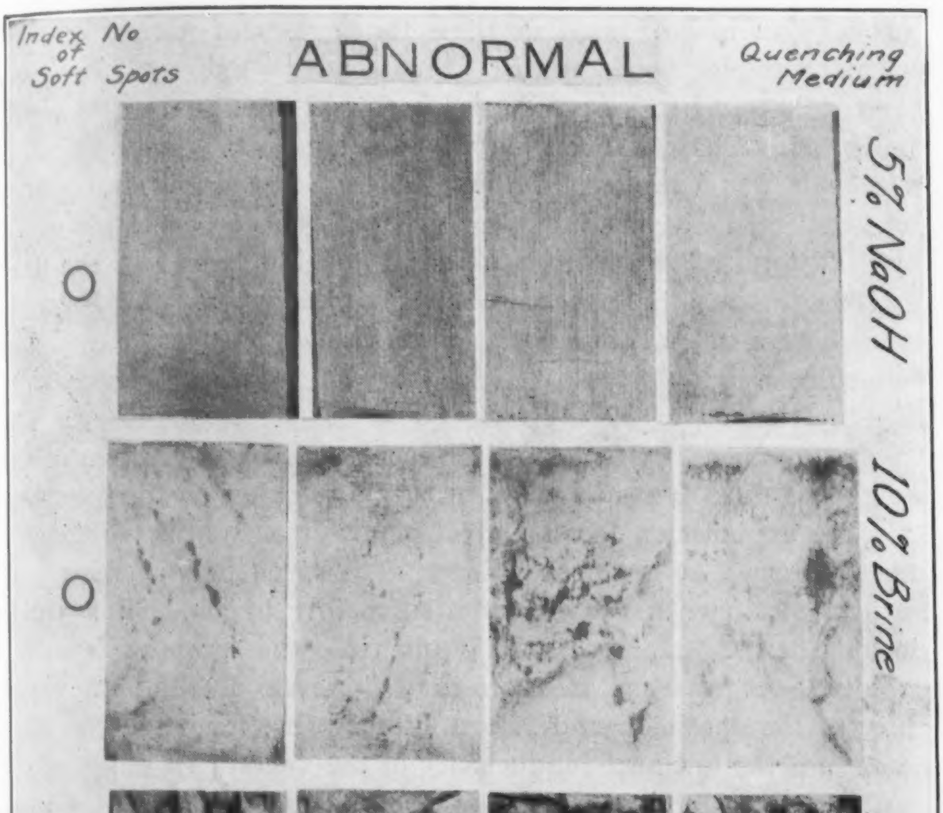

Fig. 6—The Same as the Previous Figure. The Specimens of Fig. 5 were Paired with Those of Fig. 6.

($1\frac{1}{2}$x$1\frac{1}{2}$x2 inches) used in these tests, pairs of normal and abnormal samples being heated [1425 degrees Fahr. (775 degrees Cent.), 30 min.] in a cyanide salt bath and quenched in the media indicated. The "index number of soft spots" given for each specimen was obtained in the following manner. Twenty-four Rockwell readings, C scale, were taken in rows on each side of the block, a total of 96 readings for the four side faces. In the hard martensitic areas the average reading was about 65. Readings below 60 were taken into account as an indication of softness. The following weights were given to the soft readings:—from 60 to 55—1; from 55 to 50—2; from 50 to 45—3; below 45—4. The "index number of soft spots" for each specimen is the sum of the weights of the soft readings out of the 96 readings on the specimen

The explanation for the effect of dissolved gas in the quenching water may be given as follows. The speed of quenching possible to attain with water is limited mainly by its boiling point. So long as the water is in the liquid state the specimen is cooled rapidly. As soon as steam forms, however, bubbles of vapor cling to the specimen and retard heat abstraction from the steel because of the low heat conductivity of the vapor. In water which contains dissolved gas, the gas is evolved upon heating at a temperature considerably below the boiling point of the water. The evolved gas may then act in the same way as steam to prevent heat conduction from the specimen, thus in effect lowering the boiling point of the water. In the photographs of the surfaces of the specimens quenched in tap water and boiled water plus oxygen, the soft spots were located in the discolored areas. The discolorations themselves, however, should not be considered as a direct cause of the soft spots; they are simply a witness of the presence of the oxidizing gas. The effect in producing soft spots was similar when an inert gas like nitrogen, which produced no discolorations, was dissolved in the water.

Water generally contains about 2 per cent by volume of dissolved air (about 1.3 per cent nitrogen and about 0.7 per cent oxygen) depending somewhat on the seasonal changes in temperature. The amount of dissolved air does not differ very greatly for water of different localities. The carbon-dioxide content, however, varies considerably from about 0.2 per cent in mountain river water to as high as 5 per cent in deep limestone well water. A

large proportion of the dissolved carbon-dioxide in deep well water is combined with calcium carbonate as bicarbonate, but the carbon dioxide is readily evolved upon heating, whence the name temporary hard water. In a few rough trial quenching tests made with the hard water of Canton, Ohio, to see if this water which is reputed to have a high carbon-dioxide content, would produce more soft spots than the Washington water with a low carbon dioxide content negative results were obtained. It is well, however, while discussing the effect of air dissolved in quenching water, to mention also the possible effect of other gases like carbon dioxide, which may be present in large amounts in some localities.

In the photographs of the surfaces of the quenched specimens it will be observed that the extent of the discolored areas is alike in the normal and abnormal samples, but that the latter have the larger "index numbers of soft spots." Where a gas bubble adhered to an abnormal sample and gave a discolored area a soft spot was usually formed, the cooling at the spot evidently being slower than the critical cooling rate necessary for the formation of martensite for that type of steel. Normal steel appeared to have a lower critical rate, since the slower cooling in the discolored areas was often still fast enough to give martensite; fewer discolored areas were soft in the normal steel than in the abnormal steel. Incidentally, it may be pointed out, that quenching tests and hardness surveys so made afford a very delicate means of revealing any difference in the critical cooling rate between two steels, it being possible by adjusting the size of specimen and the kind and temperature of the quenching medium to get into the critical range. Slight differences in the critical rate will then overthrow the balance of the reaction to one side or the other, giving either the Ar′ transformation to troostite, or the Ar″ transformation to martensite, with their decided and easily measured differences in hardness. In the same way slight differences in cooling rates of quenching media may be observed, as in the case of the effect of dissolved air in water described above. Benedicks[8], while making direct measurements of the cooling power of water thought he noticed an effect of dissolved air, but finally decided that his measurements showed no perceptible difference between aerated water and distilled water. This result may be called in question, however,

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[8]C. Benedicks. Cooling power of liquids, quenching velocities, etc. *Journal*, Iron and Steel Institute (1908) 77, p. 153.

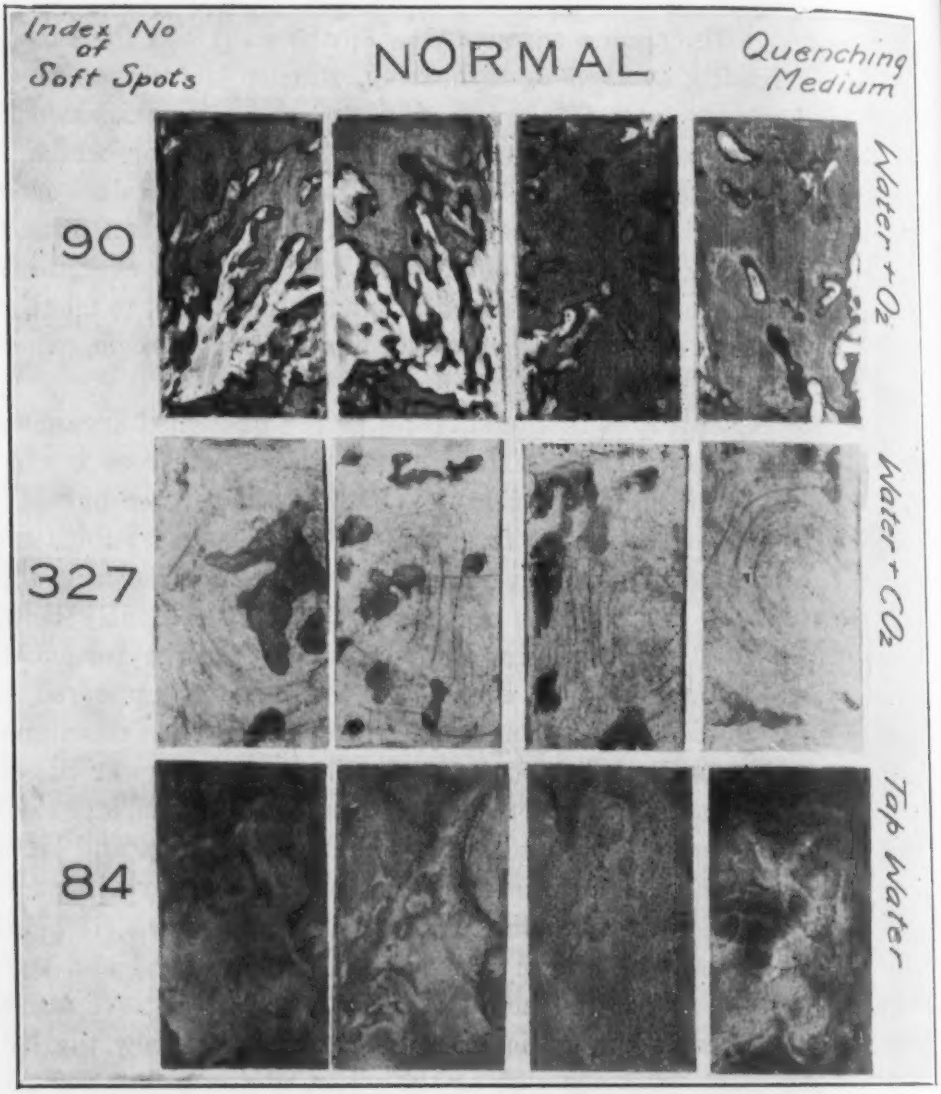


Fig. 7—The Same as the Previous Figure. The Last Specimen was Heated in an Electric Furnace with Access to Air, Instead of in a Cyanide Salt Bath, Before Quenching in the Tap Water. Note the Scale on the Surfaces.

since in the same work he also concludes that brine does not surpass water in cooling power.

The appearance of the soft spots in cross-section may be seen in Figs. 9 and 10. Fig. 9 shows cross-sections, natural size, of carburized normal and abnormal steel blocks, quenched from a cyanide salt bath into tap water, deeply etched with hot 1:1 hydrochloric acid. The difference in grain size between the normal and abnormal sample is noticeable. In deep etching, the troostitic areas in the

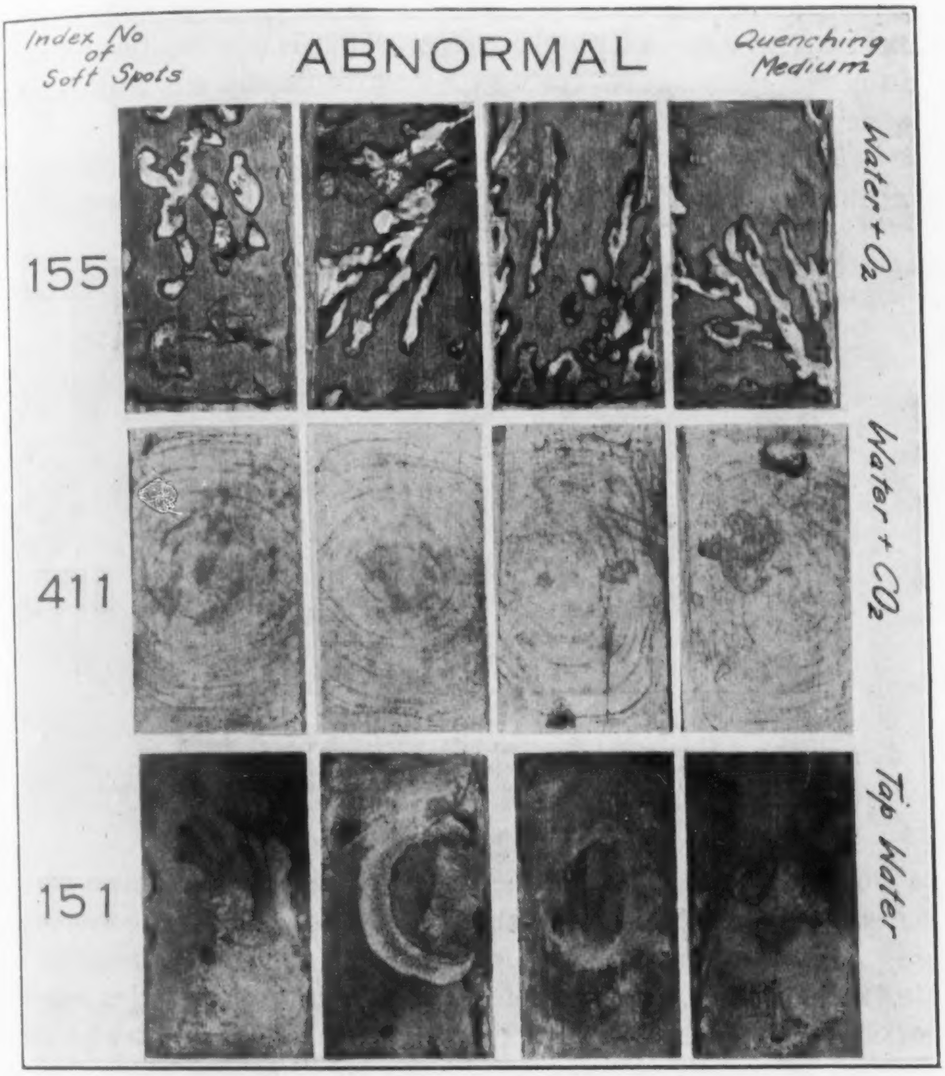


Fig. 8—The Same as the Previous Figure. The Specimens of Fig. 7 were Paired with Those of Fig. 8.

carburized layers appear lighter in color than the martensitic areas, the effect being directly opposite to that in light etching for microscopic examination. It can be seen that the troostitic areas in the abnormal steel were greater in extent than in the normal steel. Fig. 10 shows micrographs of soft spots in the cases of the above samples. In the abnormal steel, the soft spots were more completely troostitic; in the normal steel there was generally some martensite present together with the troostite, especially in the transition zone between the case and core. The difference in the form of the cementite be-

tween the normal and abnormal steel is plain. The white layer at the extreme edge in both photomicrographs is martensitic and is due to nitride penetration during the heating in the salt bath prior to quenching.

Table I shows the results of Rockwell hardness surveys of a number of carburized and quenched specimens of normal and

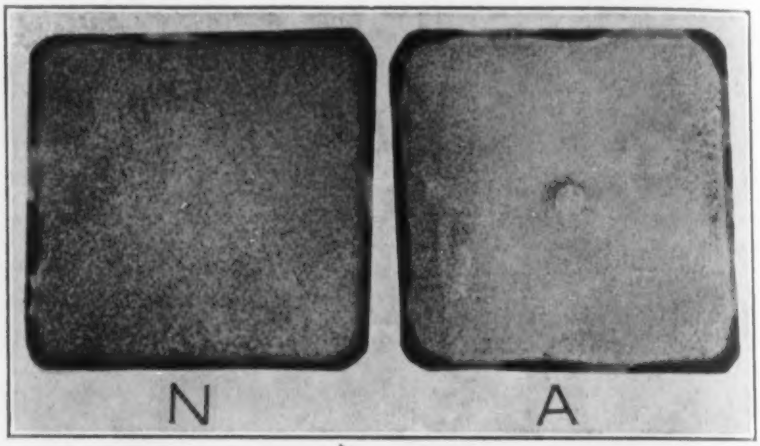


Fig. 9—Cross-sections of a Pair of Normal and Abnormal Steel Blocks Heated in Cyanide and Quenched in Tap Water; Deeply Etched with Hot 1:1 Hydrochloric Acid. In the Carburized Layers, the Dark Portions are Hard and the Light Portions are Soft Spots. It can be Seen that there are Larger Soft Areas in the Abnormal Specimen. Natural Size.

abnormal steel. The specimens used were blocks similar to the ones shown in Figs. 5, 6, 7, and 8, and had structures corresponding to the extremes of the normal and abnormal structures illustrated in Fig. 1. The method of obtaining the "index number of soft spots" has been described above. The specimens were treated in pairs and were heated for 30 minutes at 1425 degrees Fahr. (775 degrees Cent.) before quenching.

The data in Table I show a consistent difference in the number of soft spots between normal and abnormal steel and clearly indicate that abnormal steel is more prone to give soft spots than normal steel. It should be noted that the samples used exhibited the extremes of the normal and abnormal structure. No quenching tests have as yet been made of the grades intermediate in structure in regard to coalescence of the cementite, or of the fine-grained steels showing only slight coalescence of the cementite. The data of Table I also show that with the use of a drastic quenching medium, such as sodium chloride brine or sodium hydroxide

Table I

Index Numbers of Soft Spots of Pairs of Normal and Abnormal Carburizing Steels Heated[a] and Quenched in Different Media

Pair No.	Heating Bath	Quenching Bath		Index No. of Soft Spots Normal	Index No. of Soft Spots Abnormal
1	air atmosphere[b]	tap water at 16° C		84	200
2	air atmosphere[b]	tap water at 11° C		9	11
3	air atmosphere[b]	tap water at 11° C		21	86
4	air atmosphere[b]	tap water at 16.5° C		12	90
5	air atmosphere[b]	tap water at 17.0° C		1	21
6	air atmosphere[b]	tap water at 17.0° C		6	45
7	air atmosphere[b]	tap water at 17.0° C		0	96
8	gas atmosphere[c]	tap water at 17.0° C		135	276
9	gas atmosphere[c]	tap water at 17.0° C		87	118
10	gas atmosphere[c]	tap water at 11 ° C		1	22
11	gas atmosphere[c]	tap water at 10 ° C		17	35
12	78 $BaCl_2$ + 22 NaCl	tap water at 8 ° C		122	193
13	78 $BaCl_2$ + 22 NaCl	tap water at 12 ° C		11	131
14	78 $BaCl_2$ + 22 NaCl	tap water at 13 ° C		48	168
15	cyanide salt bath	tap water at 12 ° C		43	112
16	cyanide salt bath	tap water at 12 ° C		52	102
17	cyanide salt bath	tap water at 12 ° C		4	17
18	cyanide salt bath	tap water at 10 ° C		1	1
19	cyanide salt bath	tap water at 15 ° C		0	43
20	cyanide salt bath	tap water at 16 ° C		19	37
21	cyanide salt bath	tap water at 16 ° C		17	48
22	cyanide salt bath	tap water at 15 ° C		24	57
23	cyanide salt bath	tap water at 14 ° C		17	49
24	cyanide salt bath	tap water at 14° C		26	64
25	cyanide salt bath	tap water at 9° C		28	50
26	cyanide salt bath	tap water at 13° C		34	65
27	cyanide salt bath	tap water at 8° C		49	173
28	cyanide salt bath	tap water at 8° C		52	149
29	cyanide salt bath	tap water at 19° C		0	10
30	cyanide salt bath	tap water at 28° C		1	153
31	cyanide salt bath	tap water at 20° C		2	14
32	cyanide salt bath	tap water at 28° C		3	20
33	air atmosphere	boiled water 21° C		66	158
34	air atmosphere	boiled water 23° C		14	126
35	air atmosphere	boiled water 10° C		12	67
36	air atmosphere	boiled water 10° C		12	2
37	gas atmosphere	boiled water 11° C		1	27
38	gas atmosphere	boiled water 12° C		2	68
39	gas atmosphere	boiled water 24° C		126	321
40	gas atmosphere	boiled water 25° C		217	321
41	18% $BaCl_2$ 22% $NaCl_2$	boiled water 12° C		14	25
42	cyanide salt bath	boiled water 8° C		0	5
43	cyanide salt bath	boiled water 9° C		4	35
44	cyanide salt batn	boiled water 3° C		0	21
45	cyanide salt bath	boiled water 3° C		1	5
46	cyanide salt bath	boiled water + oxygen O_2	15° C	90	155
47	cyanide salt bath	boiled water + oxygen O_2	11° C	36	128
48	cyanide salt bath	boiled water + hydrogen	8° C	32	55
49	cyanide salt bath	boiled water + hydrogen	8° C	27	61
50	cyanide salt bath	boiled water + nitrogen	14° C	41	165
51	cyanide salt bath	boiled water + nitrogen	14° C	107	144
52	cyanide salt bath	boiled water + nitrogen	12° C	38	146
53	cyanide salt bath	boiled water + nitrogen	12° C	57	184
54	cyanide salt bath	boiled water + CO_2	16° C	390	428
55	cyanide salt bath	boiled water + CO_2	17° C	327	411
56	air atmosphere	15% brine[d]	16° C	0	2
57	air atmosphere	15% brine[d]	20° C	0	0
58	gas atmosphere	10% brine[d]	15° C	0	0
59	gas atmosphere	15% brine[d]	22° C	0	2
60	gas atmosphere	15% brine[d]	26° C	0	4
61	22 NaCl + 78 $BaCl_2$	into 10% brine[d]	16° C	0	0
62	22 NaCl	into 10% brine[d]	16° C	0	0
63	22 NaCl	into 10% brine[d]	18° C	0	0

[a] At 775° C for 30 minutes.

[b] 'Air atmosphere' refers to heating in an ordinary electric muffle furnace which allows access to a limited amount of air.

[c] 'Gas atmosphere' refers to heating in an electric muffle furnace filled with iluminating gas.

[d] Brine refers to sodium chloride brine.

Table I—(Continued)

Index Numbers of Soft Spots of Pairs of Normal and Abnormal Carburizing Steels Heated and Quenched in Different Media

Pair No.	Heating Bath	Quenching Bath		Index No. of Soft Spots Normal	Index No. of Soft Spots Abnormal
64	22 NaCl + 78 $BaCl_2$	into 10% brine at	12° C	0	0
65	22 NaCl + 78 $BaCl_2$	into 10% brine[d]	13° C	0	0
66	22 NaCl + 78 $BaCl_2$	into 10% brine[d]	17° C	0	0
67	22 NaCl + 78 $BaCl_2$	into 10% brine[d]	19° C	0	0
68	22 NaCl + 78 $BaCl_2$	into saturated brine[d]	18° C	0	0
69	22 NaCl + 78 $BaCl_2$	into saturated brine at	18° C	0	23
70	cyanide salt bath	into 10% brine at	13° C	0	0
71	cyanide salt bath	into 10% brine at	14° C	0	0
72	cyanide salt bath	into 10% brine at	11° C	0	0
73	cyanide salt bath	into 10% brine at	13° C	0	0
74	cyanide salt bath	into 10% brine at	17° C	0	0
75	cyanide salt bath	saturated brine at	7° C	0	0
76	cyanide salt bath	saturated brine at	10° C	0	0
77	cyanide salt bath	saturated brine + carbon dioxide	10° C	58	155
78	cyanide salt bath	saturated brine + carbon dioxide	10° C	112	278
79	cyanide salt bath	10% brine + carbon dioxide	8° C	167	314
80	cyanide salt bath	10% brine + carbon dioxide	8° C	145	274
81	air atmosphere	into 5% sodium hydroxide	24° C	0	0
82	air atmosphere	into 5% sodium hydroxide	22° C	0	0
83	gas atmosphere	into 5% sodium hydroxide	23° C	0	0
84	gas atmosphere	into 5% sodium hydroxide	20° C	0	0
85	gas atmosphere	into 5% sodium hydroxide	21° C	0	0
86	gas atmosphere	into 5% sodium hydroxide	22° C	0	4
87	22 NaCl + $BaCl_2$	into 5% sodium hydroxide	12° C	0	0
88	cyanide salt bath	into 5% sodium hydroxide	8° C	0	0

solution, the formation of soft spots can be completely prevented in *both* normal and abnormal steel. The quenching solution recommended by Merten was not tried in these experiments since elimination of soft spots was readily obtained with brine or a sodium hydroxide solution. Of the secondary results of the quenching tests, the effect of dissolved gas in the quenching water has already been discussed. It is interesting to note the large number of soft spots that were obtained with brine containing dissolved carbon dioxide. Although in some of the tests more soft spots were obtained upon heating in an air or gas atmosphere where scaling was possible than upon heating in a cyanide salt bath, the data in Table I indicate that as regards the elimination of soft spots, the type of quenching medium used is of much greater importance than the manner of heating. A word may be said as to the advisability of changing from water quenching to a more drastic medium like brine, pressure spray, or sodium hydroxide solution. With case-hardened articles there is small danger from cracking. The question is whether drastic quenching will increase warpage. No experiments were made on this point but it would seem that warpage is perhaps more a result of uneven temperature gradients than steep gradients, and it is possible that there would

be no increase in troubles from warpage if the more drastic methods of quenching were adopted to avoid soft spots.

V. Normal and Abnormal Tool Steels

The characteristics of the normal and abnormal structure present in the low carbon carburizing steels, have also been found to exist in the high carbon tool steels.[9] In order to bring out the differences between the normal and abnormal types it is necessary to make the McQuaid-Ehn carburizing test with the tool steels just as with the carburizing steels. Fig. 11 shows the structures of a normal and abnormal tool steel of the following composition: Normal—C. 0.90 per cent; Cr. 0.15 per cent; Abnormal—C. 0.90 per cent; Mn. 0.23 per cent; Cr. 0.01 per cent. In abnormal steel the tendency for coalescence of the cementite in the hypereutectoid zone manifests itself, after suitable treatment, also in the interior of the steel. Fig. 12 shows the structure of samples of normal and abnormal tool steel cooled together slowly through the critical range. It can be seen that in the abnormal steel the coalescence or spheroidization of the cementite has progressed further than in the normal steel.

In quenching tests of the above tool steels the abnormal samples showed themselves more prone to give soft spots than the normal samples. 1½-inch square blocks similar to the carburized blocks could not be obtained, and instead smaller samples, 1¼-inch round, 2 inches long were used. These gave less soft spots than the larger carburized blocks, but the indications were clear, as shown in Table II, that the abnormal samples were more prone to give soft spots. The specimens were heated for 30 minutes at 775 degrees Cent. before quenching. Brine quenching was not used with the tool steels since it was evident from the preceding work that complete hardening would be obtained in this way. Ninety-six Rockwell readings were taken on each specimen, as with the carburized blocks.

Fig. 13 shows cross-sections of quenched normal and abnormal tool steel samples deeply etched with hot 1:1 hydrochloric acid. The dark outer ring in each specimen shows the depth of the hardened layer. The normal steel hardened considerably more deeply than the abnormal steel. An arrow indicates a soft spot

[9] F. G. Sefing, Abnormal vs. Normal Tool Steels. Michigan State College, Lansing, Michigan, Bulletin No. 5.

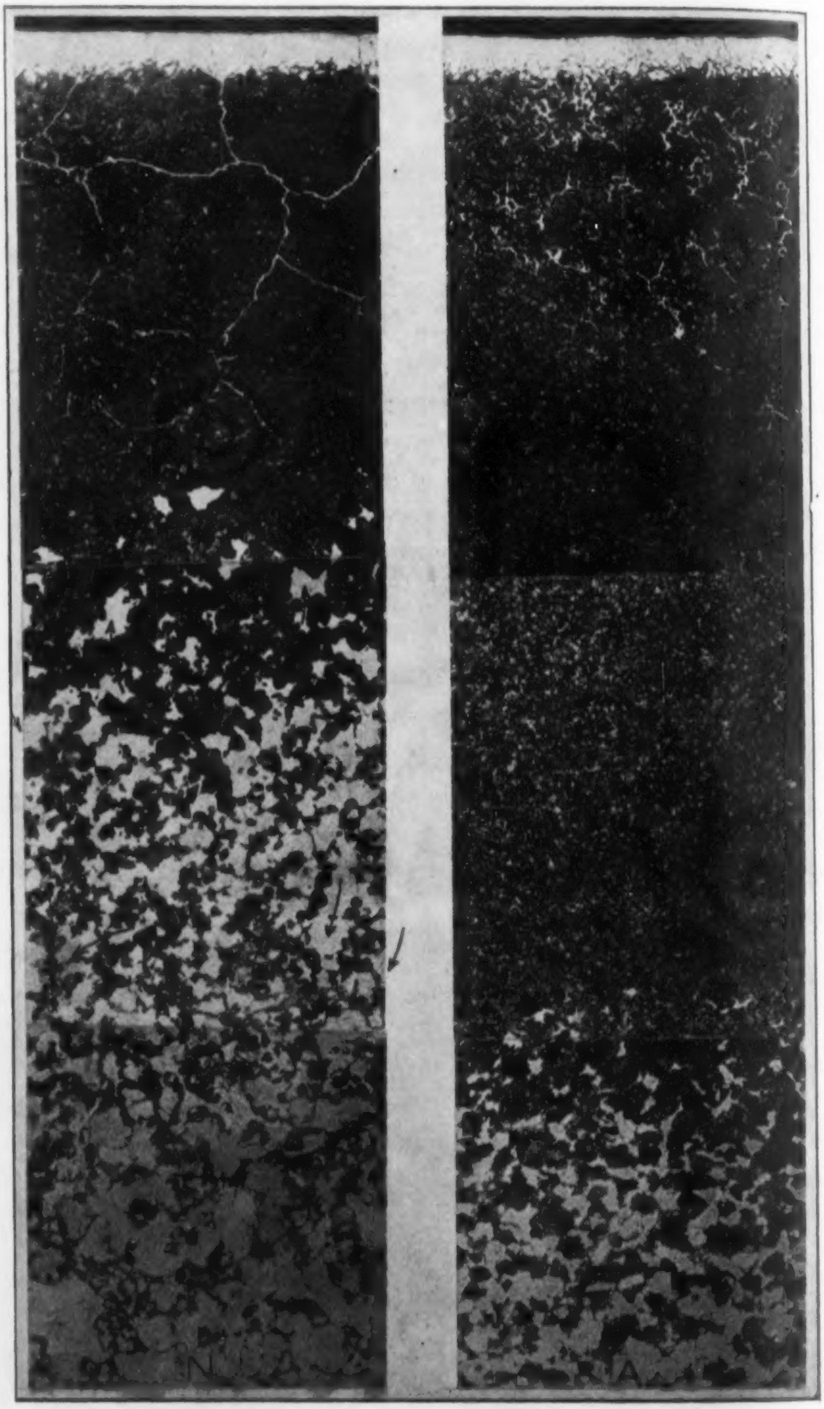


Fig. 10—Cross-section Through Soft Spots in Normal and Abnormal Case-hardened Steel. In the Carburized Layer of the Abnormal Steel, the Soft Spot is Completely Troostitic, Whereas, in the Normal Steel there is Some Martensite Present Together with the Troostite. The Martensite is Indicated by Arrows. The White Border at the Extreme Edge is Martensite Due to Nitrogen Penetration During the Heating in the Cyanide Bath Prior to Quenching. 100 x.

in the abnormal steel. Neither of these samples contained vanadium which is often stated to cause steel to harden less deeply than a corresponding plain carbon steel. It is not considered that the slight amount of chromium in the normal steel (normal steel 0.15 Cr; abnormal steel 0.01 Cr.) produced the difference in the hardening properties; this appeared to be largely, if not entirely, due to the difference in the degree of normality between the two samples. It may be pointed out here that just as with the carburizing steels a different degree of normality or abnormality might be more suitable for different purposes, so with the tool steels. Some might desire a normal steel to ensure uniform hardness. Others might prefer an abnormal steel because of the finer grain and for the reason that it hardens less deeply. In pneumatic tools it is often advisable to use a less deeply hardening steel to counteract brittleness.

VI. Cause of Normality and Abnormality

Once we accept the existence of normal and abnormal steel our attention centers on the explanation. According to Ehn, abnormality is caused by dissolved or submicroscopic particles of oxides. In discussion of his work other causes were suggested, such as high nitrogen content and high phosphorus content. In tests at the Bureau of Standards the structures of wrought-iron, of electrolytic iron, of highly phosphorized iron, of nitrogenized iron, of the fused-in metal of steel welds,[10] of small steel ingots low in manganese, melted in a laboratory induction furnace, and of unfinished steel sampled during the progress of a heat, all showed marked differences, after carburization, from the structures of normal steel. Any irregularity, in fact, is plainly reflected in the appearance of the carburized structure. From this viewpoint there may be any number of possible causes of "abnormal" steel. In the sense, however, of the term abnormal steel used in this paper referring to a definite type of structure in *commercial* steels, the actual causes of normality and abnormality are limited to the conditions obtaining in practical steel making. Ordinary chemical analyses have failed to show any relation between the amounts of the usual elements present in steel such as sulphur, manganese, phosphorus, and silicon, and normality and abnormality. Therefore the effect of the ordinary variations in content of these elements on

[10] See ref. 3.

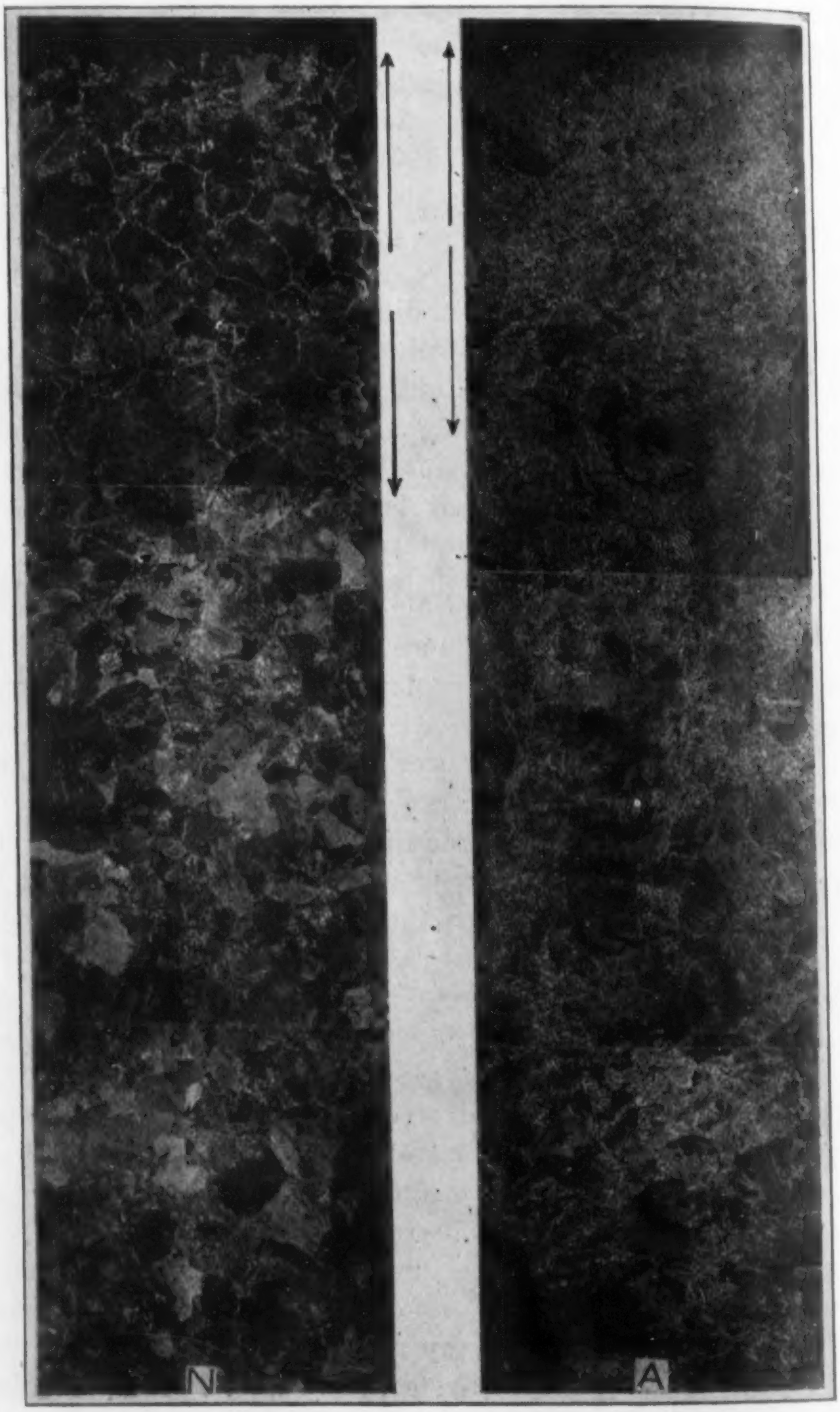


Fig. 11—The Carburized Layers of Normal and Abnormal Tool Steel Specimens. The Same Characteristics of the Normal and Abnormal Structure Appear in the Tool Steel as in the Carburizing Steel. The Arrows Indicate the Extent of the Hypereutectoid Zone. 100 x.

abnormality must apparently be ruled out, which brings us back to Ehn's theory.

Table II

Index Numbers of Soft Spots of Normal and Abnormal Tool Steels

Pair No.	Heating Bath	Quenching Bath		Index Soft Normal	No. of Spots Abnormal
1 T	air atmosphere	tap water at	29° C	0	31
2 T	air atmosphere	tap water at	28° C	1	30
3 T	air atmosphere	tap water at	17° C	0	3
4 T	air atmosphere	tap water at	17° C	0	0
5 T	air atmosphere	tap water at	17° C	1	1
6 T	Cyanide salt bath	tap water at	28° C	0	15
7 T	Cyanide salt bath	tap water at	28° C	0	14
8 T	Cyanide salt bath	tap water at	20° C	0	0
9 T	Cyanide salt bath	tap water at	19° C	0	2
10T	Cyanide salt bath	tap water at	28° C	0	22
11T	Cyanide salt bath	tap water at	28° C	0	3
12T	Cyanide salt bath	tap water plus oxygen	28° C	0	7
13T	Cyanide salt bath	tap water plus oxygen	28° C	0	24
14T	Cyanide salt bath	tap water plus oxygen	30° C	0	20
15T	Cyanide salt bath	tap water plus oxygen	30° C	0	30

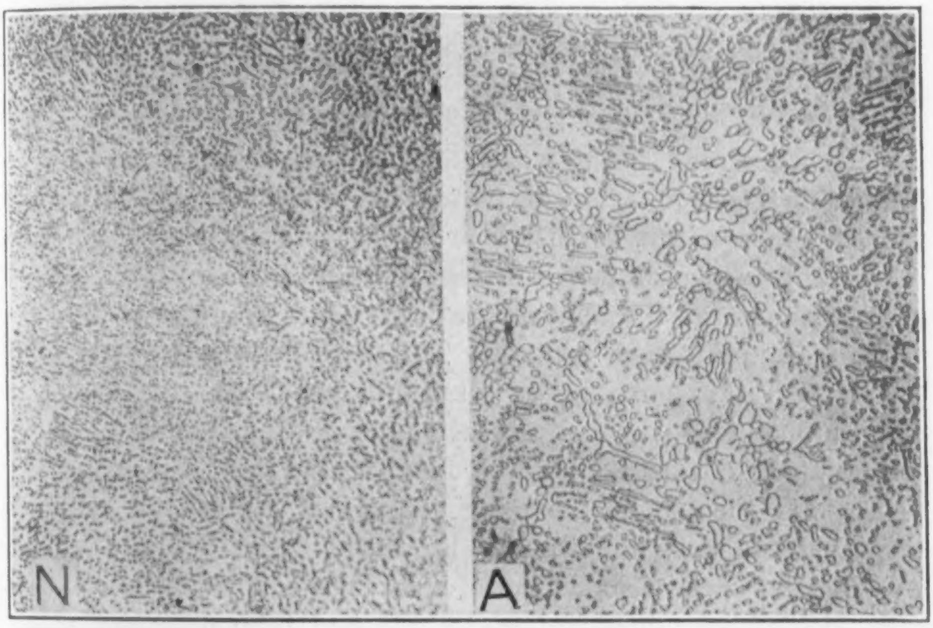


Fig. 12—The Structure of Normal and Abnormal Tool Steel Specimens Cooled Together Slowly Through the Critical Range. The Coalescence or Spheroidization of the Cementite has Progressed Further in the Abnormal Steel than in the Normal Steel. 500 x.

By its nature Ehn's theory is not easily susceptible of direct experimental proof. Microscopic examinations, with and without the aid of etching reagents have thus far failed to detect inclusions in commercial abnormal steel to which the obstruction to grain growth and coalescence of the cementite might be attributed, although further work in this direction is necessary.

Gas analyses of normal and abnormal steel have not given very consistent or at least easily interpreted and conclusive results. Table III gives the results of gas analyses by the vacuum fusion method of normal and abnormal specimens.

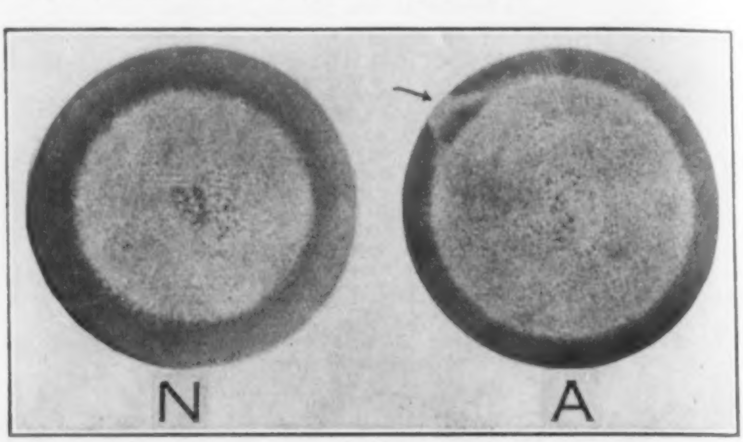


Fig. 13—Cross-sections of Quenched Normal and Abnormal Tool Steel Cylinders; Deeply Etched with Hot 1:1 Hydrochloric Acid. The Dark Outer Ring Shows the Depth of Hardening. The Arrow Indicates a Soft Spot in the Abnormal Specimen. Natural Size.

In Table III the nitrogen and hydrogen contents show no noticeable relation between normality and abnormality, nor do the oxygen contents, with which we are mainly concerned, indicate the presence of more oxides in the abnormal steel. On the contrary most of the abnormal samples fall into Group I of the table, of lower oxygen content. This does not disprove the oxide theory for it is possible, as Ehn indicated, that the degree of abnormality may depend not simply on the amount of oxides in the steel, but rather on the form and size of the oxide particles. On the whole, the oxygen analyses yielded no confirmatory evidence that abnormality is caused by oxides in the steel.

Tests with the deoxidation of steel on a commercial scale, however, yielded very positive results. It had been observed in preliminary experiments that steel treated with aluminum in the mold was abnormal. In spectroscopic analyses[11] of a large number of commercial normal and abnormal steel specimens it was likewise found that abnormality was generally associated with high aluminum content. Fig. 14 shows the results of these spectroscopic analyses. The question arose whether aluminum was actually the cause of abnormality or whether it was merely a con-

[11]Spectroscopic analyses by N. F. Meggers, Physicist, Bureau of Standards.

Table III

Results of Gas Analyses of Normal and Abnormal Steel Specimens by the Vacuum Fusion Method[a]

Specimen No.	Structure of Case	Chemical Composition C %	Mn %	P %	S %	Si %	Gas Content (uncarburized stock) O_2 %	N_2[b] %	H_2 %
Group I (Lower oxygen content)									
A	Abnormal	.23	.52	.027	.030	.23	Nil	.012	Nil
B	Intermediate	.21	.52	.032	.030	.19	Nil	.009	Nil
C	Abnormal	.46	.71				Nil		.0002
D	Abnormal	.19	.48	.028	.025	.06	.0017	.015	.0001
E	Abnormal	.21	.51	.024	.029	.22	.0020	.011	.0001
F	Intermediate	.21	.43	.009	.042	.006	.0025	.005	.004
G	Abnormal	.16	.42				.0032	.003	
H	Normal	.17	.43				.0023		Nil
I	Normal	.14	.51				.0034		Nil
J	Normal	.21	.17				.0032		.0001
K	Abnormal	.19	.42	.009	.043	.006	.0033	.003	Nil
L	Abnormal	.22	.41				.0038		
M	Abnormal	.19	.48	.004	.027	.03	.0050	.005	.0005
N	Abnormal	.26	.52	.019	.036	.009	.0062	.004	.0004
O	Abnormal	.12	.34			.01	.003		.0006
P	Abnormal	.12	.39			.004	.003		.0009
Q	Abnormal	.13	.37			.008	not detected		Nil
Group II (Higher oxygen content)									
R	Normal	.19	.41	.004	.050	.002	.0092		.001
S	Normal	.16	.44	.009	.019	.05	.0113	.005	.0007
T	Normal	.25	.46	.014	.027	.13	.0117	.004	.0007
U	Normal	.17	.60	.012	.021	.03	.0118	.004	.0006
V	Abnormal	.08	.33				.0165		.0005
W	Abnormal	.07	.37	.014	.021	.013	.0318	.010	Nil
X	Normal	.12	.37			.01	.008		.0004
Y	Normal	.12	.27			.07	.037		Nil
Z	Normal	.12	.28				.012		.0007
AA	Normal	.12	.38			.08	.018		.0001
BB	Normal	.14	.35			.07	.017		.0001
CC	Normal	.14	.25			.07	.021		.0001

[a]Analyses by W. P. Barrows and R. J. Kranauer, Bureau of Standards.
[b]Combined nitrogen by the Allen method.

comitant—the larger quantity of aluminum having been used perhaps to counteract a condition which would have given abnormal steel with or without the addition of aluminum. Table IV shows the results of deoxidation tests of killed and effervescent steel to determine this point carried out in a steel plant.[12] The steel was made in 100-ton open-hearth furnaces and cast into 3-ton ingots.

As shown in Table IV, mold additions of aluminum and likewise of ferrovanadium produced abnormality in both the killed and effervescent steel. Ferrovanadium was chosen because of its known effect in producing fine grain. The additions of aluminum and ferrovanadium used in the mold were just sufficient to kill the ingots of effervescent steel. Figs. 15, 16, 17 and 18 show photomicrographs of the carburized layers of bars from the reg-

[12]These tests were made possible through the courtesy of the Central Alloy Steel Corporation, Canton, Ohio.

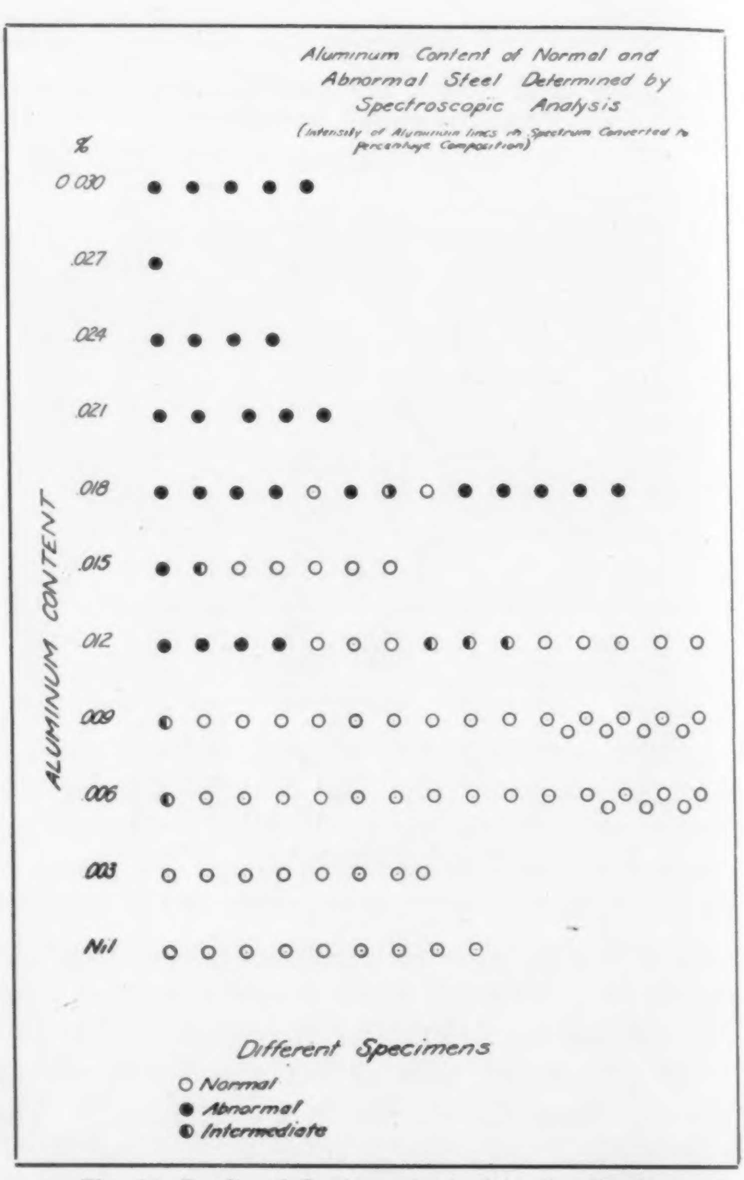


Fig. 14—Results of Spectroscopic Analyses for Aluminum of Normal and Abnormal Steel Specimens. About Half of the Specimens were Commercial Steel; the Other Half were Experimental Specimens, Made on a Commercial Scale.

ular ingots of the killed and effervescent steel and of bars from ingots of the same heat treated with aluminum and ferrovanadium in the mold. The samples from the regular ingots were normal; those from the treated ingots were abnormal. In the carburized layers of the regular effervescent samples the cementite envelopes were somewhat thicker than in the regular killed samples; the grain size was large, however, with no marked separation of the

cementite from the ferrite so that it appears justifiable to classify the regular effervescent samples as normal.

The important point was noted that in the killed steel about the same amount of aluminum per ton of steel was added in the ladle, as a matter of regular practice, as was used in the experimental mold additions to the killed and effervescent steel. However, the ladle additions in contrast to the mold additions, apparently had no effect in producing abnormality. The effect of the aluminum and ferrovanadium additions appeared to be the

Table IV

Effect on McQuaid-Ehn Structure of Additions of Aluminum and Ferro-Vanadium in Mold, to Killed and Effervescent Steel

Type of Steel	Ingot No.	Mold Addition.	Structure of Carburized Layer.
.11-.14% C Killed Steel	7	4 pounds Shot Al.	Abnormal
	8	4 pounds Shot Al.	Abnormal
	9	25 pounds 37% Ferrovanadium	Abnormal
	10	Regular Ingot, no mold addition.	Normal
.11-.14% C Effervescent Steel	7	4 pounds Shot Al.	Abnormal
	8	4 pounds Shot Al.	Abnormal
	9	25 pounds 37% Ferrovanadium	Abnormal
	10	Regular Ingot, no mold addition.	Normal
.11-.14% C Effervescent Steel	7	5 pounds Shot Al.	Abnormal
	8	5 pounds Shot Al.	Abnormal
	9	25 pounds 37% Ferrovanadium 1½ pounds Shot Al.	Abnormal Abnormal
	10	Regular Ingot, no mold addition.	Normal
.13-.16% C 1½% Ni, Killed Steel.	7	25 pounds Ferrovanadium	Abnormal
	8	Regular Ingot, no mold addition.	Normal

same with the killed steels, to which aluminum had already been added in the ladle, as with the effervescent steels to which no aluminum additions had previously been made.

The results given in Table IV clearly indicate that abnormality, if it is not caused by oxides in the steel, is at least closely bound up with the manner of deoxidation. It is significant that ladle additions of aluminum did not produce abnormality whereas mold additions did. In both instances, a large proportion of the aluminum may be presumed to have become oxidized, and it is interesting to consider that the difference in effect may be due to a difference in the form or size of the oxide particles, the finer particles causing abnormality. When aluminum is added in the ladle the aluminum oxide has a chance to coalesce into larger particles (some of it, of course, may rise to the slag). When aluminum is added in the mold the oxide particles are more likely to remain in a fine state of subdivision. A similar reason may account for the difference in action between silicon and

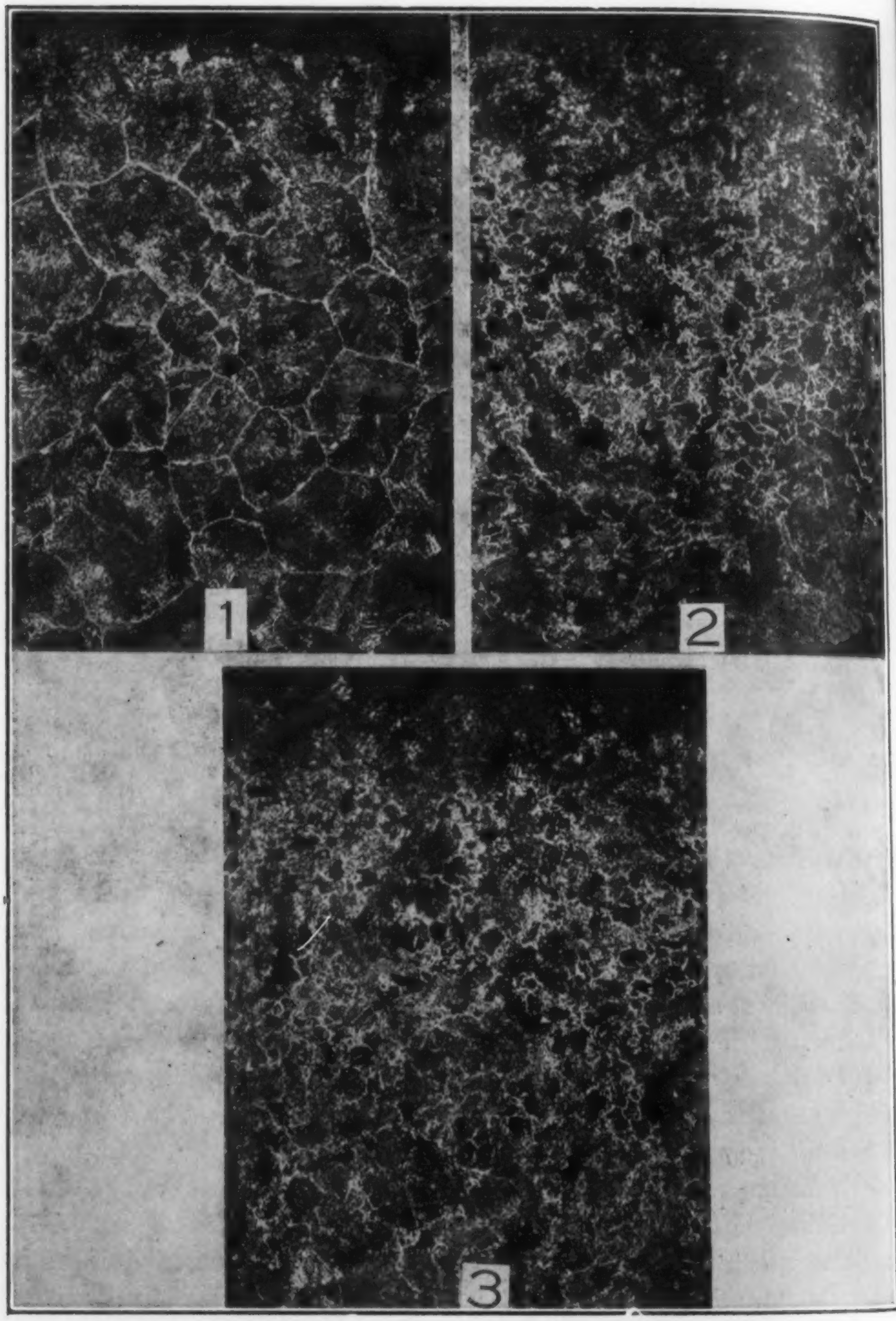


Fig. 15—Killed Carbon Steel—0.11 to 0.14 per cent Carbon.
1—Regular Commercial Ingot; Normal.
2—Three Ton Ingot from Same Heat with 4 Pounds of Shot Aluminum Added in Mold; Abnormal.
3—Three Ton Ingot from Same Heat with 25 Pounds of 37 per cent Ferrovanadium Added in Mold; Abnormal. 100 x.

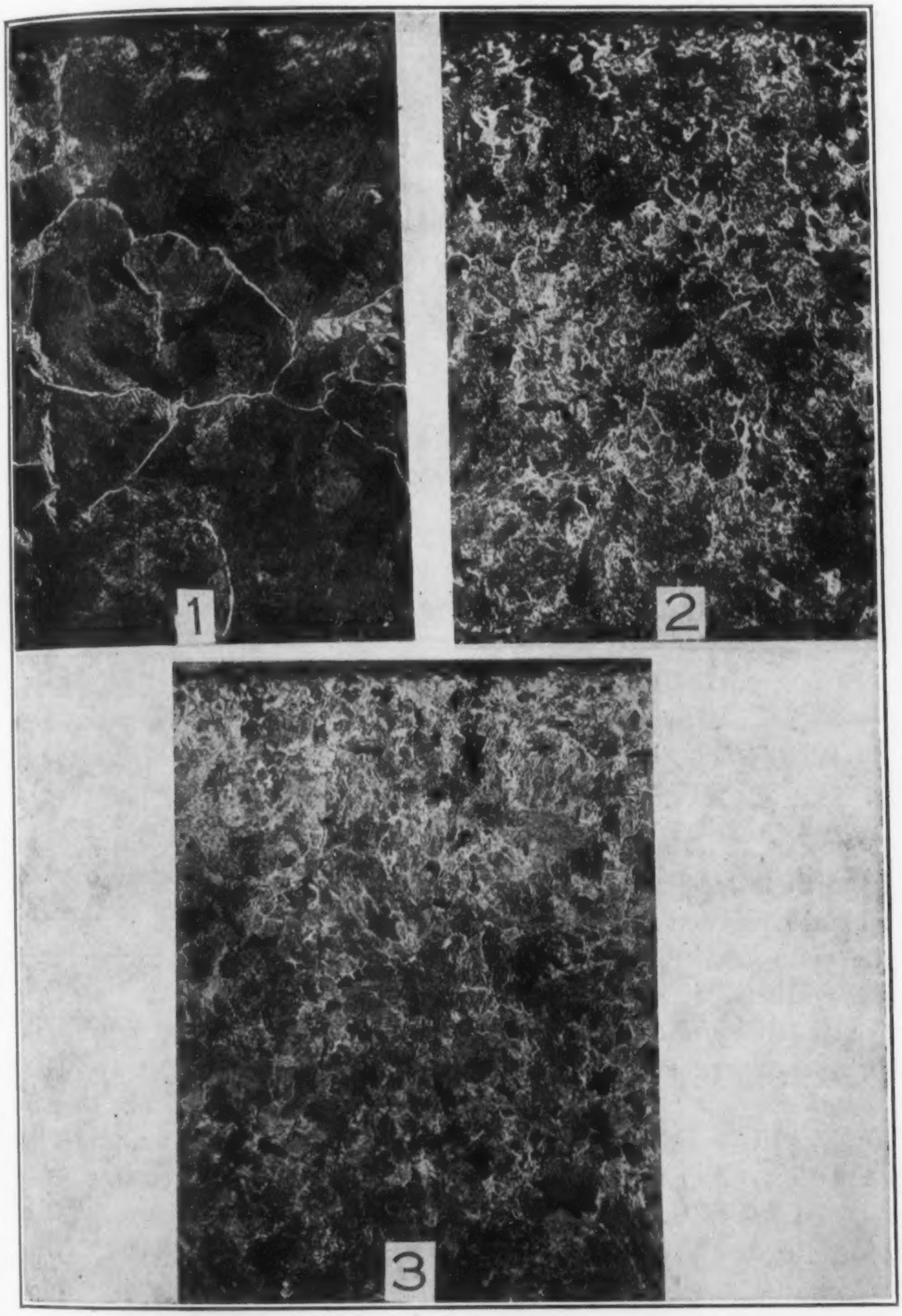


Fig. 16—Effervescent Carbon Steel—0.11 to 0.14 per cent Carbon.
1—Regular Commercial Ingot; Normal.
2—Three Ton Ingot from Same Heat with 4 Pounds of Shot Aluminum Added in mold; Abnormal.
3—3-Ton Ingot from Same Heat with 25 Pounds of 37 per cent Ferrovanadium Added in Mold; Abnormal. 100 x.

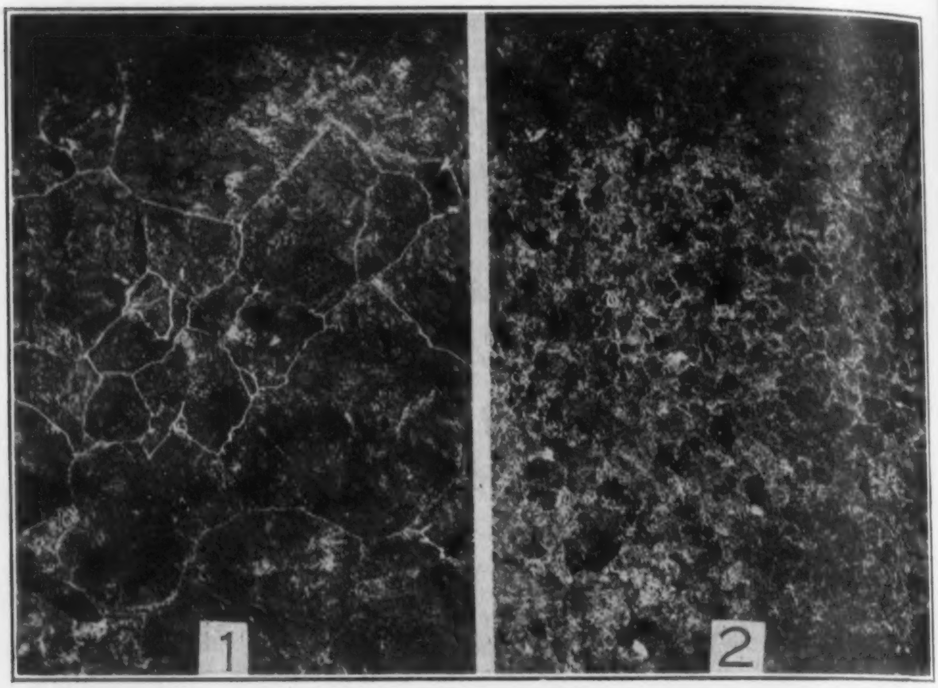


Fig. 17—Killed Nickel Steel—0.5 per cent Nickel.
1—Regular Commercial Ingot; Normal.
2—3-Ton Ingot from Same Heat with 25 Pounds of 37 per cent Ferrovanadium Added in Mold; Abnormal. 100 x.

aluminum. Fig. 19 shows photomicrographs of the carburized layers of two ingots of 0.12 per cent carbon effervescent steel from the same heat, the ingots killed in the mold with ferrosilicon and aluminum respectively. The silicon-treated steel is normal; the aluminum-treated steel is abnormal. The oxides formed from the addition of silicon are more fusible than those formed from the addition of aluminum, and may, therefore, more readily coalesce into larger particles. It has been suggested that perhaps the reason why the addition of aluminum in the ladle did not produce abnormality was that the aluminum reacted in some way with the ferrosilicon which was added in the ladle at the same time.

An interesting observation of the deoxidation tests was that additions of aluminum gave the same results as additions of ferrovanadium. The effect of vanadium in producing fine grain is well known; it is probably largely due to obstruction to grain-growth by fine particles of vanadium oxide. The intriguing possibility suggests itself of producing the same effect by inexpensive additions of aluminum as by expensive alloying additions of vanadium. A dis-

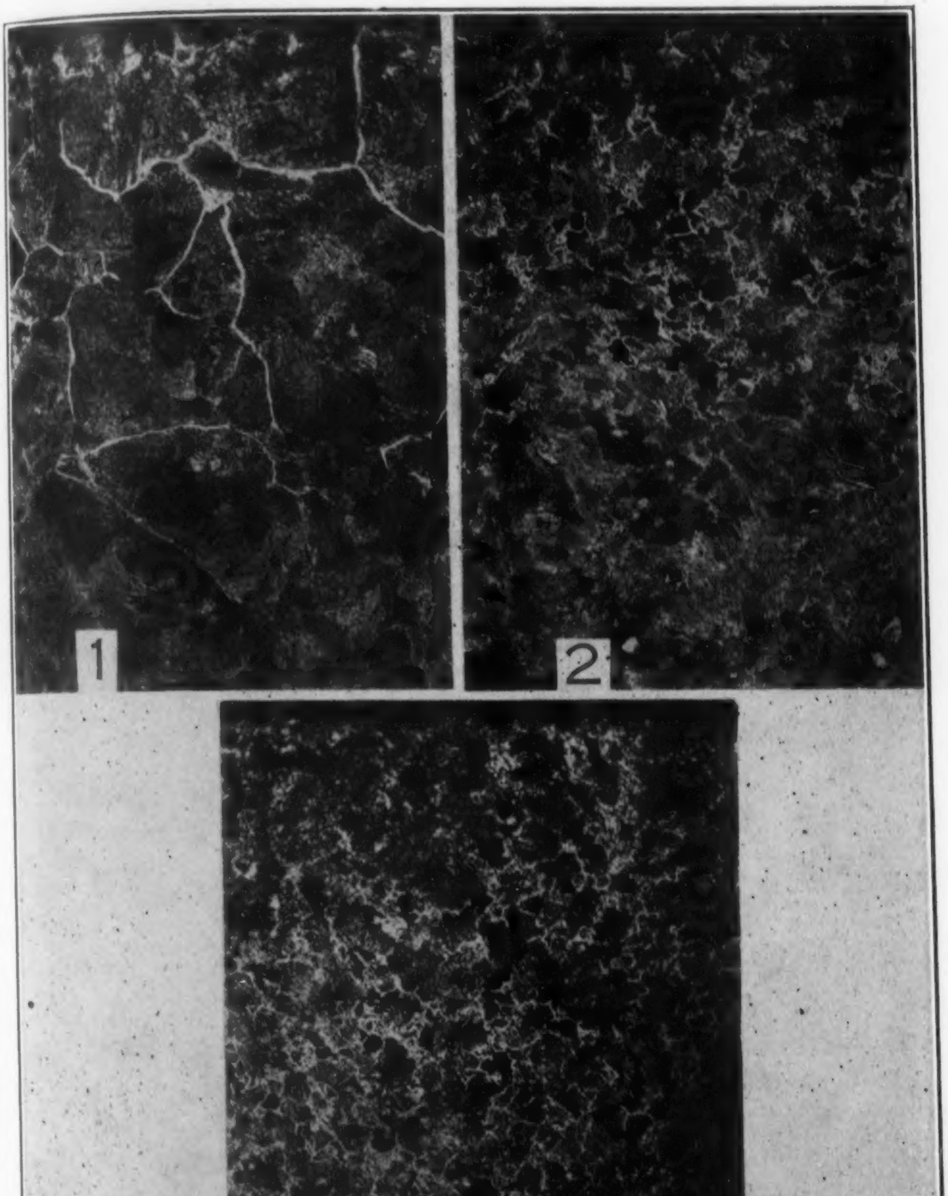


Fig. 18—Effervescent Carbon Steel—0.11-0.14 per cent Carbon.
1—Regular Commercial Ingot; Normal.
2—3-Ton Ingot from Same Heat with 4 Pounds Shot Aluminum Added in Mold; Abnormal.
3—3-Ton Ingot from Same Heat with 25 Pounds of 37 per cent Ferrovanadium Added in Mold; Abnormal. 100 x.

advantage of aluminum is the tendency of its oxides to segregate, which might be counteracted perhaps by adding the aluminum in less concentrated form, as an alloy with iron. That vanadium steel resembles abnormal steel in its hardening properties was indicated under the discussion of normal and abnormal tool steel. Users of

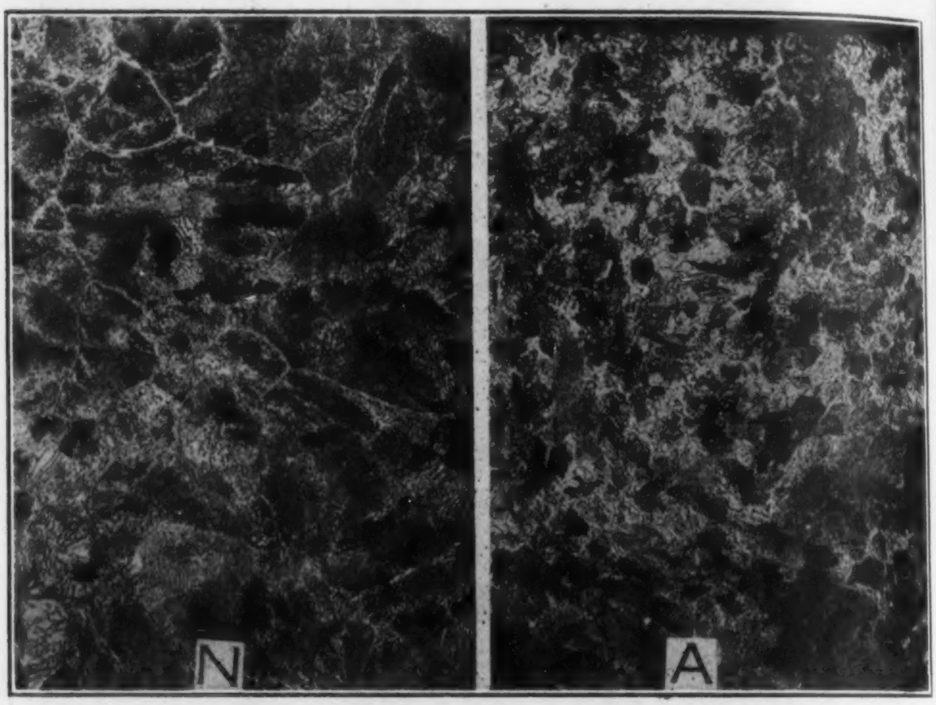


Fig. 19—Carburized Layers of Two Ingots of 0.12 per cent Carbon Effervescent Steel from the Same Heat, the Ingots Deoxidized with Silicon in the Mold and Aluminum in the Mold Respectively. The Silicon Treated Steel is Normal; the Aluminum Treated Steel is Abnormal. 100 x.

carbon-vanadium steel state that it is less deeply hardening than plain carbon steel.

The deoxidation tests described above plainly indicate that abnormality is tied up with the manner of deoxidation. A series of McQuaid-Ehn tests of ladle test ingots taken during the progress of open-hearth heats also showed that the deoxidation treatment is the main factor, overshadowing apparently any differences in the degree of normality that may have been produced during the melting and refining of the steel. Fig. 20 shows the carburized layers of a series of ladle test ingots from an open-hearth heat of 0.20 per cent carbon killed steel. It can be noted that at a stage during the refining of the heat the steel showed decided coalescence of the cementite. After deoxidation, however,

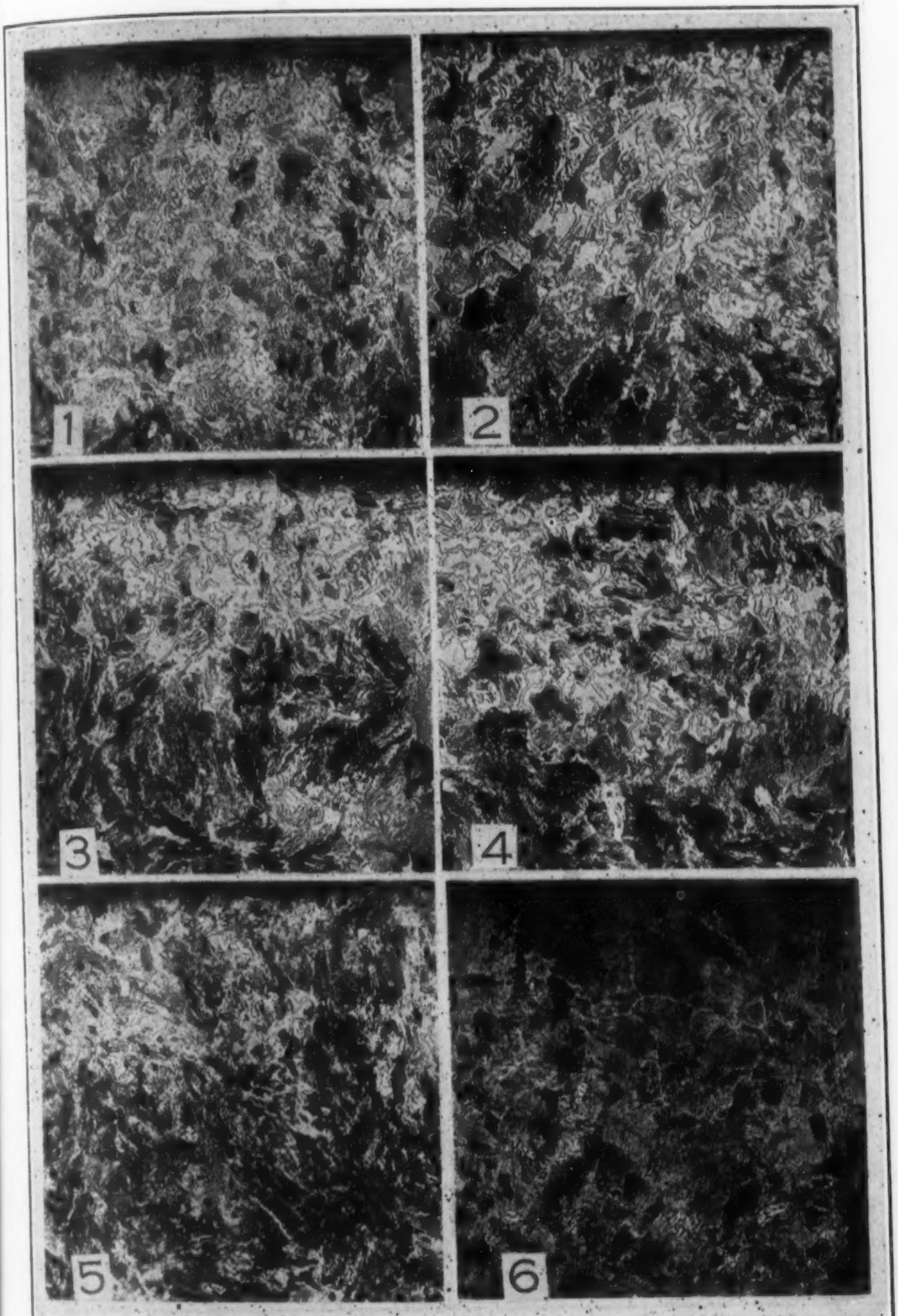


Fig. 20—1-5. Carburized Layers of Ladle Test Ingots Taken During the Progress of a 0.20 per cent Carbon Steel Open-hearth Heat. The Micrographs Show that this Heat Before Deoxidation was Pronouncedly Abnormal. 6. Carburized Layer of the Finished Steel After Deoxidation; the Structure is Normal. 100 x.

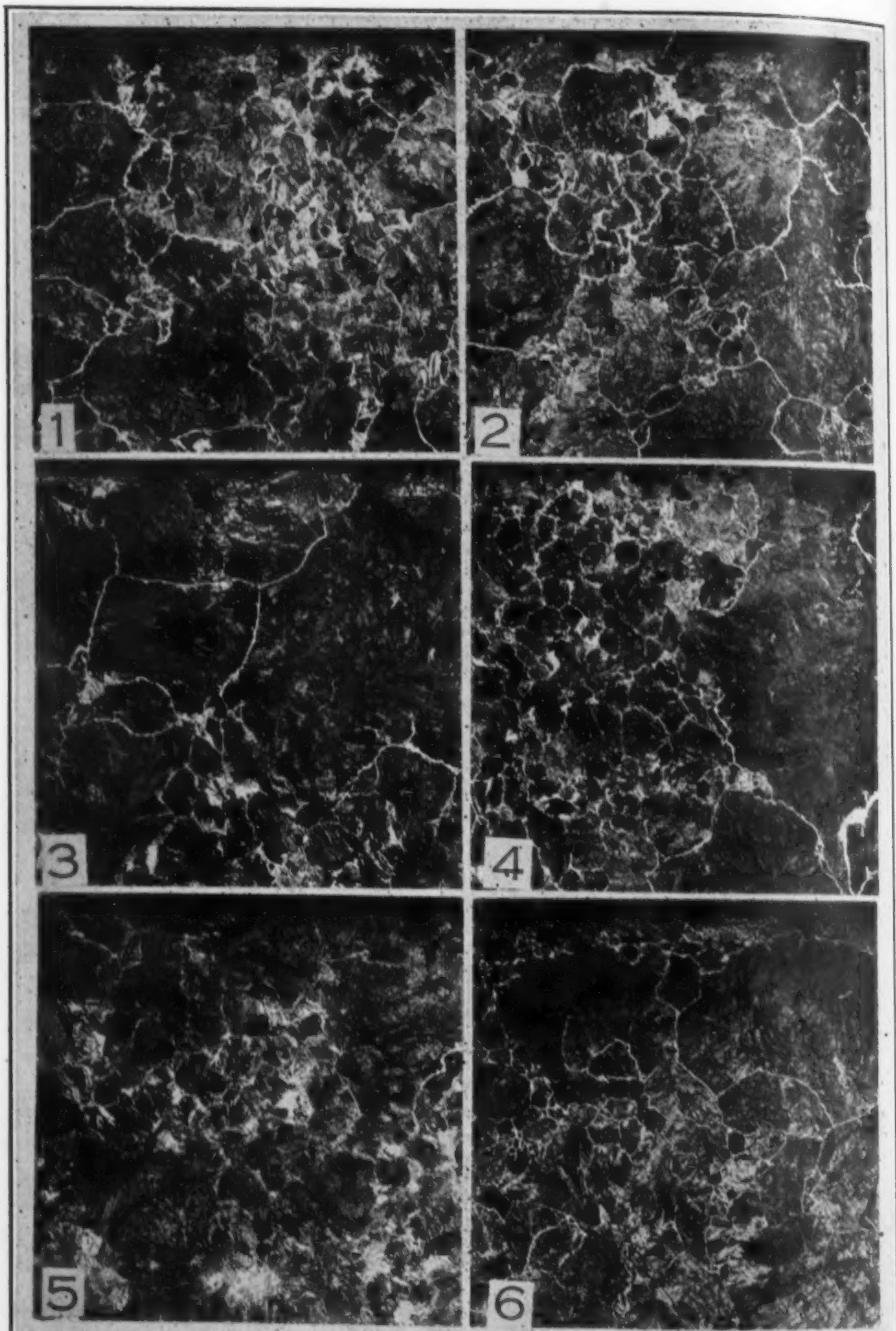


Fig. 21—1-5. Carburized Layers of Ladle Test Ingots Taken During the Progress of a 0.30 per cent Carbon, 0.60 per cent Chromium, and 1 per cent Nickel Steel Open-hearth Heat. This Heat did not Appear to go Through a Pronouncedly Abnormal Stage, as did the Heat Shown in Fig. 20. The Structures 1-5 May be Called Almost Normal. 6. The Carburized Layer of the Finished Steel After Deoxidation; the Structure is Likewise Normal. 100 x.

it became perfectly normal, the McQuaid-Ehn structure apparently reflecting mainly the deoxidizing treatment used. Fig. 21 shows the carburized layers of a series of ladle test ingots from another open-hearth heat in which the steel while in the furnace showed very little coalescence of the cementite. This steel after deoxidation was likewise normal.

The fact (discussed under Section II, The Normal and Abnormal Structure) that variations in the mechanical treatment and heat treatment of the steel has practically no effect on the degree of normality, indicated that abnormality had its origin in the making of the steel. The experiments above show that it is connected with the deoxidation procedure in steel making. As for the specific effects of particular deoxidizers, definite conclusions can hardly be drawn from the comparatively few tests that were made. However, the results obtained in the deoxidation tests with aluminum bear out the results of the spectroscopic analyses which showed that abnormality in commercial carbon carburizing steel was almost invariably accompanied by a high aluminum content. From the above results it would appear that with a modicum of experimentation a steel maker ought to be able to produce normal and abnormal steel at will, subject, of course, to the limitations of chemical composition. It would hardly be possible, for instance, to produce a coarse-grained vanadium steel. It should be mentioned that the McQuaid-Ehn test which is so very sensitive to variations in the melting and deoxidation procedure of the steel, may become a very useful test in the hands of the steel maker for studying and controlling his product.

Summary

The foregoing report should be considered essentially as one of progress rather than as the result of a *completed* investigation. There still remain some questions unanswered, particularly with respect to the fundamental reason for the difference in the behavior of steels when carburized. So far as possible in this report, speculation on this point has been avoided and only when there was considerable supporting evidence has "theorizing" been resorted to. The following points are believed to be well substantiated by the results of the investigation.

1. The microstructures of different steels, initially showing no decided differences in composition, after carburization differ

very noticeably and vary from a structure consisting of relatively large grains of well-formed pearlite surrounded by cementite envelopes, at one extreme, to relatively small irregular grains in which the cementite, both of the pearlite and of the envelopes, shows marked coalescence. The carburized layer on some steels is often considerably thicker than that produced on others of essentially the same composition by an identical carburizing treatment. The terms "normal" and "abnormal" have been used to designate these two conditions.

2. The general condition of "abnormality" in steel may be conveniently considered as "grain-size abnormality" and "structural abnormality", the first of these often exists independently of the second.

By a normalizing treatment, sometimes repeated several times in succession, steel showing "grain size abnormality" has been made to assume a more normal condition when carburized. Such heat treatment has not been found to have any appreciable effect upon steel showing well defined "structural abnormality".

3. Hardness surveys of carburized steels, graded as typically normal and abnormal on the basis of their microstructure, after being given identical hardening treatments, in pairs, have shown:—

(a) With *drastic* quenching both types of steel hardened essentially the same, that is, no surface soft spots were found.

(b) With less drastic coolants, the abnormal steels showed a greater tendency toward soft spots than did the normal steels regardless of the method of heating prior to quenching or of quenching, except as noted in (a).

4. The presence of dissolved gas in any liquid used for quenching steel is an important factor in producing surface soft spots as the gas is released from solution by the immersion of the hot metal. The results of hardness surveys of specimens quenched in tap water were quite different from those obtained in the same water after being boiled to expel the dissolved gas or those obtained in the boiled water recharged with gas. Oxygen, hydrogen, nitrogen and carbon dioxide all behaved alike, though not to the same degree. Carbon dioxide, because of its high solubility in water had the most pronounced effect in producing soft spots. The mottled oxide film when dissolved oxygen is present is lacking in the case of the other gases.

5. Abnormal steel was found to be more affected with respect to the number of soft spots formed, by the presence of dissolved gas in the coolant than was normal steel. This may be interpreted as indicating a higher critical cooling velocity for such steel than for normal steel.

6. High carbon steels (tool steels) show the same differences when carburized as are connoted by the terms "normal" and "abnormal" for carburizing steels. Abnormal tool steels showed a greater tendency toward the production of surface soft spots upon quenching than normal tool steels.

7. Determinations of the "gas content" of steels have not given any conclusive evidence as to the real nature of abnormality.

8. The condition of the steel connoted by the term "abnormality" has its origin in the steel making process and is intimately related to the deoxidation treatment.

(a) Abnormal steel has been found often to be associated with a noticeably higher aluminum content in the finished product than is normal steel, although, on the other hand, the presence of aluminum is not a sure indication of abnormality.

(b) Experiments in the steel plant showed that both effervescing and ladle-killed steel which were normal in the finished condition could be made abnormal by the addition of aluminum in the mold, the amount of aluminum being the same as that used in the ladle addition.

(c) Ferrovanadium added in the mold to ladle-killed or effervescing steel produced an effect similar to aluminum.

(d) The most probable explanation of the structural change brought about by such additions to an otherwise normal steel is the "obstruction-to-grain-growth" hypothesis, although conclusive microscopic evidence supporting this has not yet been obtained.

9. The terms "normal" and "abnormal", as used with reference to the structural condition of steels, should not be considered as synonomous with "superior" and "inferior" but rather as indicating *suitability* for different purposes.

The general method shows promise of being a valuable one for the study of conditions existing in steel usually denoted as "quality", which affect the useful properties of the material but which cannot be directly determined and studied in the steel in its ordinary condition by means available to us at present.

NORMALITY OF STEEL

By John D. Gat

Abstract

This paper was written in order to bring better understanding of the term "normality of steel" and properties possessed by steels classified as abnormal. After conducting some experiments to demonstrate the behavior of steels having different grain size and amounts of segregated cementite, the writer dwells on the properties of "cementitic lining" present in abnormal steels arriving at the conclusion that resistance to uniform hardening is caused by high oxygen content forming a eutectoid alloy with the constituents of austenite.

FIVE years ago when Messrs. McQuaid and Ehn published their interesting paper[1] two new terms were originated and rapidly gained common usage in metallurgical parlance. As with everything new they were not accepted instantaneously but induced a considerable amount of controversy. The term *normal steel* was understood to mean a steel which after carburizing and quenching under normal conditions would harden uniformly. *Abnormal steel* after similar treatment would fail to produce a uniformly hard surface.

The data accumulated by numerous investigators confirmed the facts presented in the original paper so thoroughly that at the present time there is hardly any doubt that in the popular mind "abnormality" and "normality" are definitely connected with the properties attributed to them by the originators of these terms.

At the beginning, the McQuaid-Ehn test could answer the question only roughly. The answer was positive or negative. Experimenters, most of them decidedly practical men, soon became dissatisfied with the results furnished by this procedure. It was found, or it was thought to be, that normality is not an absolute value but one of variable magnitude. "More normal", "Less ab-

[1]H. W. McQuaid and E. W. Ehn, "Effect of Quality of Steel on Case Carburizing Results"—American Society of Mining and Metallurgical Engineers, February, 1922, and E. W. Ehn—"Influence of Dissolved Oxides on Carburizing and Hardening Qualities of Steel"—Iron and Steel Institute, May, 1922. E. W. Ehn—"Irregularities in Case Hardened Work Caused by Improperly Made Steel"—Transactions, Vol. 2, 1922, page 1177.

A paper presented before the winter sectional meeting of the society, January 19, 20, 1927, at Washington, D. C. The author, J. D. Gat, metallurgical engineer, was formerly with the Central Alloy Steel Corp., Canton, Ohio.

normal", began to be used promiscuously. The popular attention was soon detracted from all other indicators of normality to the grain size of gradation and, later, of hypereutectoid layer. It was assumed that normality and grain size go hand in hand. This allowed a subdivision of the state of normality into as many groups as was suited to the occasion.

One is liable, seeing the large grains of Fig. 1, to pass an erroneous judgment based on grain size alone as to its normality. Then, after familiarizing himself with the facts connected with the carburizing practice one may retract the statement, assuming that higher carburizing temperatures destroy the sharp distinction between the different grades of normality and only results obtained at low temperatures, such as represented in Fig. 2 can be considered reliable.

A closer study of the image structure will show that a sharply defined line of demarcation still exists between these two types of steel. A normal steel, Fig. 3, produces a hypereutectoid zone consisting of grains of definitely polygonal shape usually of the same size. The cementitic mesh is formed by straight lines of uniform thickness. In abnormal steel there is a strong tendency to have crystals in hypêreutectoid zone of more or less rounded form varying from a barely perceptible rounding of the corners and ending with almost circles, Fig. 4., irrespective of the dimensions of the grains, even if no divorce of pearlite has taken place. Cementitic mesh surrounding them sometimes forms fine uniform lines, but more often the crystals are replaced by films of varying thickness. This appearance presupposes a moderately abnormal case. In a pronounced case, the divorce of pearlite comes strongly into play and the character of the boundaries change completely.

Carburization at the different temperature ranges will show its effects on the microscopic appearance in two ways. Higher temperatures will increase the size of grains and reduce the relative percentage of cementite both present at the grain boundaries and of pearlitic crystals. A specimen which after carburization according to the McQuaid-Ehn test, i. e. at 1725 degrees Fahr. has in its hypereutectoid zone very small grains of pearlite and cementite of about the same size, will change them into fair sized crystals of pearlite surrounded by a continuous mesh of cementite provided the temperature is sufficiently high. At the same time the shape of

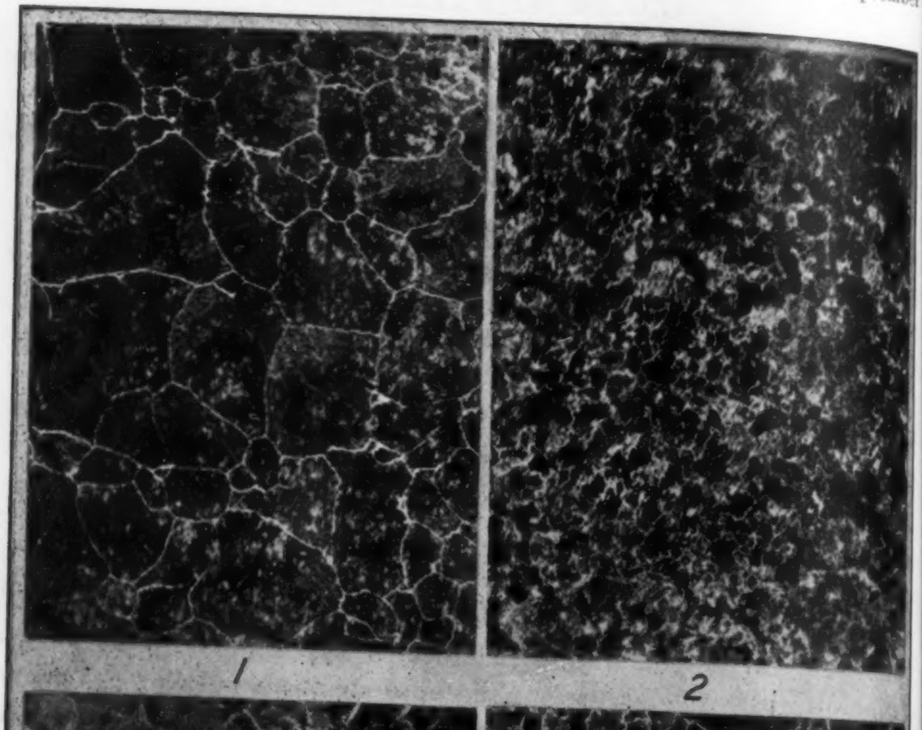


Fig. 1.—Hypereutectoid Zone of Abnormal Steel Carburized at 1850 degrees Fahr. for 6 Hours. 100x. Fig. 2.—Same as Fig. 1 but Carburized at 1725 degrees Fahr. for 6 Hours. 100x. Fig. 3.—Hypereutectoid Zone of Normal Steel Carburized at 1725 degrees Fahr. 100x. Fig. 4.—Hypereutectoid Zone of Abnormal Steel. 100x.

grains will remain decidedly abnormal and no improvement can be observed in the pattern of the cementitic mesh. The peculiar appearance of the boundaries departing from their usual, or normal straight line shape, characteristic of normal steel, shows that the cause interfering with the unimpeded crystallization of a normal steel is still present at elevated temperatures, though its tendency

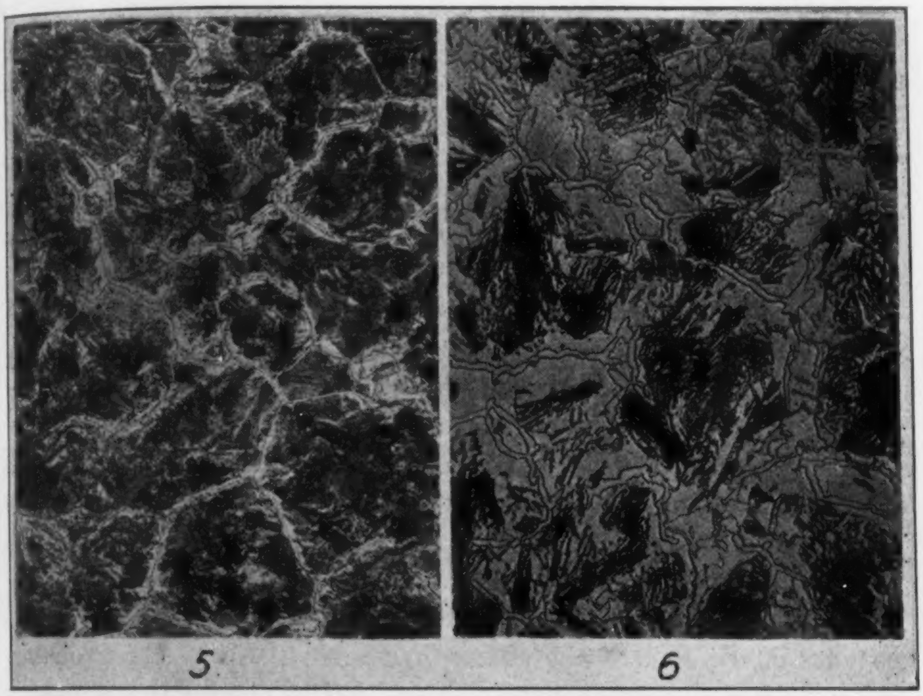


Fig. 5.—Hypereutectoid Zone of Very Abnormal Steel Carburized at 1725 degrees Fahr. for 6 Hours. 100x. Fig. 6.—Hypereutectoid Zone of Very Abnormal Steel Carburized at 1850 degrees Fahr. for 6 Hours. 100x.

toward prevention of the formation of eutectoid alloy is somewhat lessened.

In some steels carburization results in the formation in the hypereutectoid zone of very coarsely laminated pearlite or even of free ferrite present in conjunction with free cementite and the elevation of temperature will not affect the solution of the latter. Slight improvements can be seen in refining of the pearlite. Cementitic boundaries present at lower temperatures as isolated masses at the planes of contact of pearlitic grains usually unite to form a continuous mesh work. Here its character is totally different from that observed in an ordinary steel as can be seen from a comparison of Figs. 5 and 6 with any other photomicrographs

depicting the same object. The enlarged size of crystalline constituents is traceable to well-known conditions inducing grain growth.

It is interesting to note that in carburizing the temperature and time are not interchangeable. While the rise of the temperature above certain limits rapidly introduces changes, the increase of the time element fails to accomplish anything but a certain enlargement of the size of grains in the eutectoid zone and the area between it and the core. Prolonged carburization at a low temperature increases the depth of eutectoid zone, promotes grain growth in it and in the gradation zone, but does not affect in any way the hypereutectoid zone of a specimen. (Figs. 7 and 8 illustrate this point.)

Normal steel carburized at 1725 degrees Fahr. has a gradation zone (Fig. 9) consisting of a comparatively few rather large polygonal grains of about the same dimensions. Intensification of carburizing factors results in the increased size of crystals, but the increase is uniform. Fig. 10 shows that the relative dimensions of crystalline units increase in the same ratio. The growth is moderate. In abnormal steel carburized above 1725°F. normal crystallization is replaced by germination. Small somewhat rounded grains observed in normal carburizing range shown in Fig. 11 grow disproportionally (Fig. 12).

It is self-evident that as the carbon content of steel approaches 0.90 per cent the characteristic features of the gradation zone and the core permitting their use as normality indicators are almost completely obliterated.

A large number of samples made of different heats of steel containing around 0.90 per cent carbon and 1.00 per cent chromium were carburized at 1850 degrees Fahr. for 6 hours. The samples so prepared, when examined, were very little different from low carbon steels carburized at 1725 degrees Fahr. As far as the hypereutectoid zones were concerned, (the only zone suitable as an index of normality) no difference could be seen. The grains of pearlite did not reach the dimensions usually associated with high carburizing temperature and the distribution of free cementite was not, seemingly, affected at all. Many of the specimens showed a typical abnormal structure as observed at low temperatures, consisting of very small grains and masses of coagulated cementite.

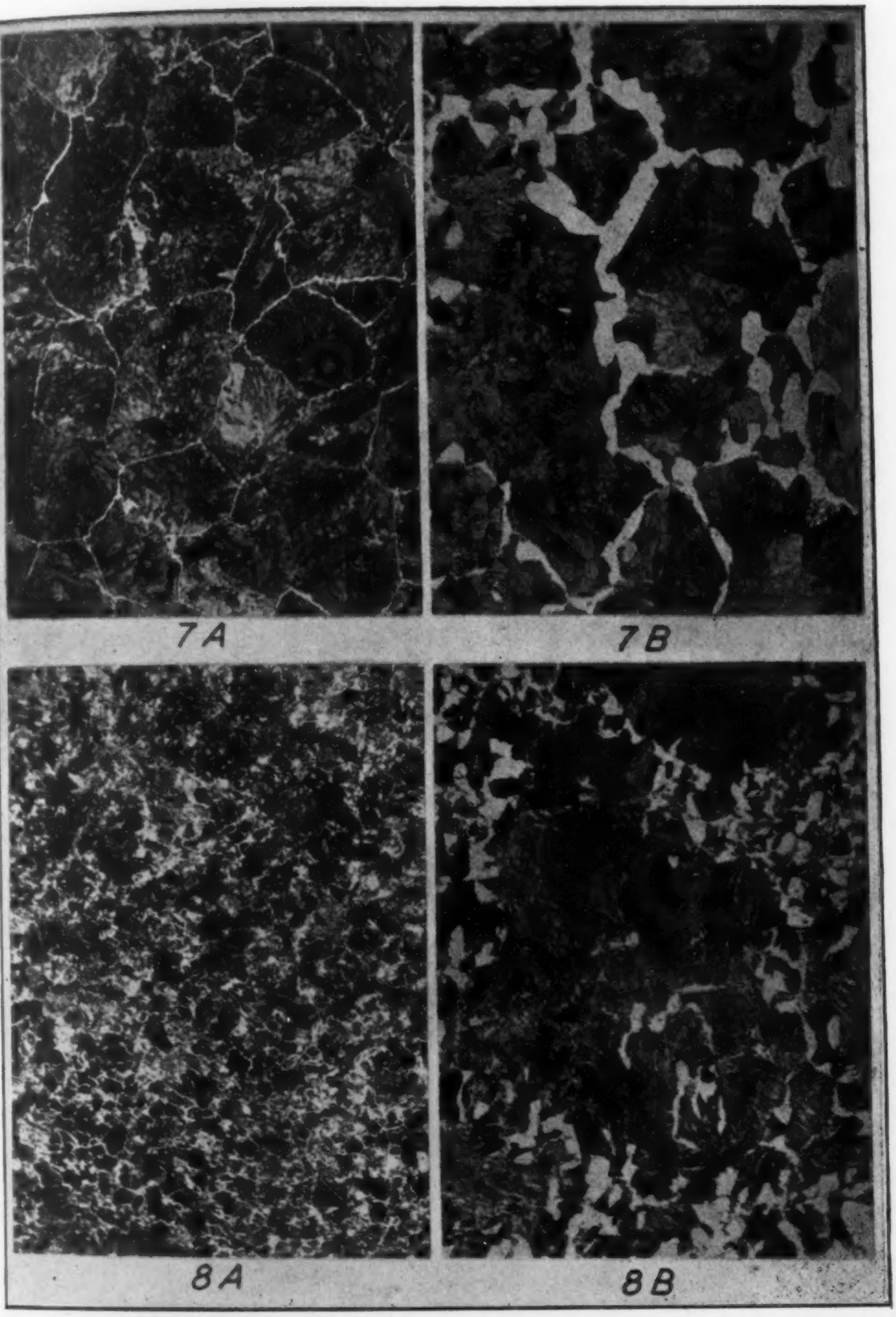


Fig. 7a.—Hypereutectoid Zone of Normal Steel Carburized at 1725 degrees Fahr. for 24 Hours. 100x. Fig. 7b—Graduation Zone of Normal Steel Carburized for 24 Hours at 1725 degrees Fahr. 100x. Fig. 8a—Hypereutectoid Zone of Abnormal Steel Carburized at 1725 degrees Fahr. for 24 Hours. 100x. Fig. 8b.—Graduation Zone of Abnormal Steel Carburized for 24 Hours at 1725 degrees Fahr. Note Excessive Grain Growth. 100x.

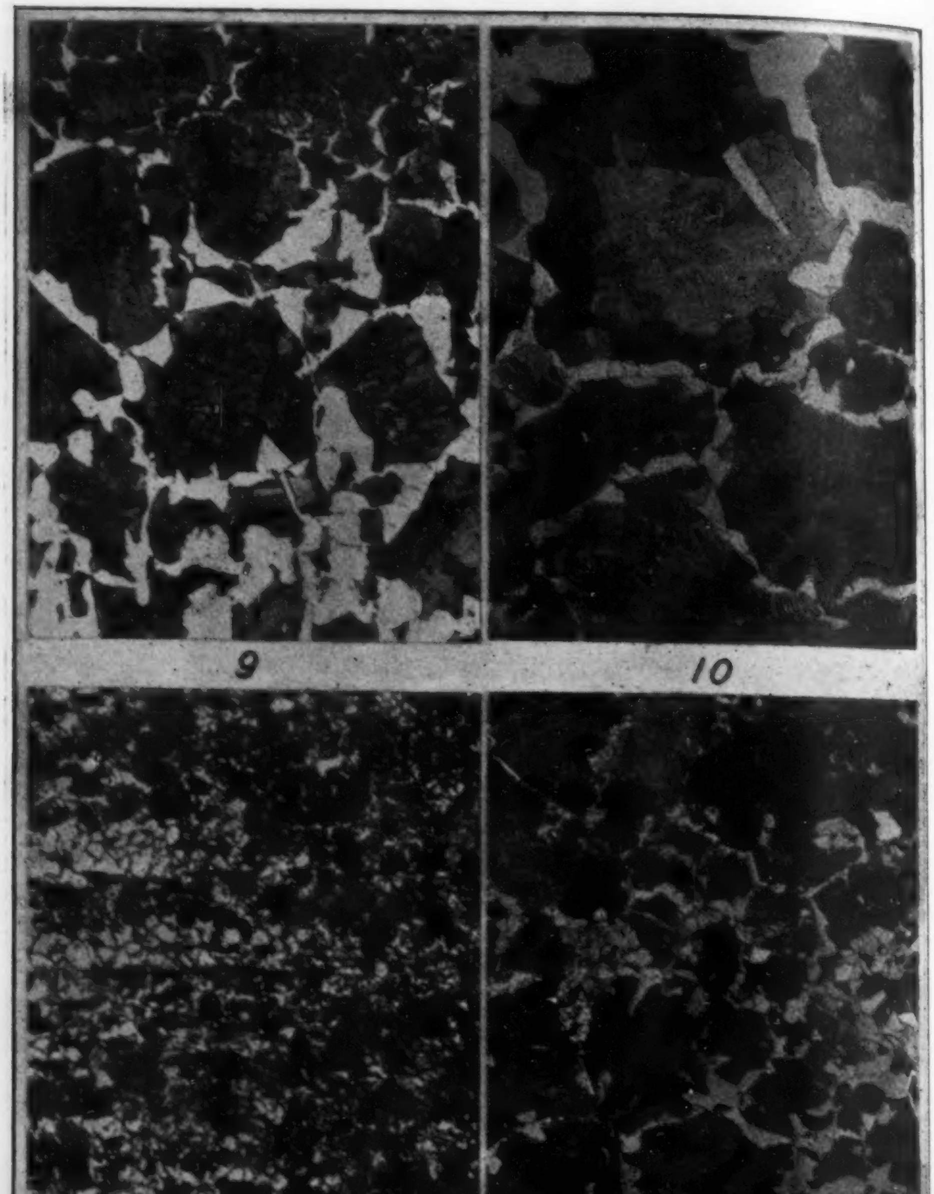


Fig. 9.—Gradation Zone of Normal Steel Carburized at 1725 degrees Fahr. for 6 Hours. 100x. Fig. 10.—Gradation Zone of Normal Steel Carburized at 1850 degrees Fahr. for 6 Hours. 100x. Fig. 11—Gradation Zone of Normal Steel Carburized at 1725 degrees Fahr. for 6 Hours. 100x. Fig. 12—Gradation Zone of Abnormal Steel Carburized for 6 Hours at 1850 degrees Fahr. 100x.

In connection with the abnormality of steel, constant reference to the grain size directs one's attention toward the possibility of some interrelation between this property of steel and the phenomena regulating grain growth in general.

To study this factor information was obtained by carburizing part of a casting as it left the mold. The remaining part of it was subjected to deformation covering a sufficient range of values to show the influence of different amounts of work. It was then carburized by a treatment, similar to the foregoing one.

A series of low carbon steels, SAE-3115, was cast into small chills to retain their cast structure. Sections of ingots so produced were carburized as usual. The rest of them were reduced, in steps, under a steam press at temperatures considerably below the critical temperature to 1.5 per cent of the original cross section and placed in the carburizing box together with the former. Photomicrographs of Figs. 13 and 14 reproduce the structure of representative specimens, i.e., those cast and those deformed to 1.5 per cent of original cross section. They show scarcely any change in normality. In all intermediate stages of reduction it was even less pronounced. In the light of these observations it is difficult to see any definite relation between grain size of specimens and their normality.

Practice, seemingly, supports this contention. In several thousand cases, sections taken from 20 x 20-inch ingots as removed from the molds were carburized and compared with specimens procured from all stages of reduction from 8 x 8-inch blooms to ¼-inch cold-rolled wire. In not a single instance could any pronounced variation be recorded.

To demonstrate the results produced by normalizing, three ¼-inch round bars were kept at 1600 degrees Fahr. for 15 minutes and cooled in air. Figs. 15 and 16 are conclusive evidence that as far as the shape or size of the cementitic mesh is concerned, that no changes were produced.

Normalizing previous to carburizing does not in any way change the state of normality of a given specimen, though it may slightly increase the size of crystals in the gradation zone of the abnormal type.

The influence of annealing was investigated by preparing sets of S.A.E. steels, numbers 3115, 3130, 3150 and subjecting them to different annealing treatments before standard carburization.

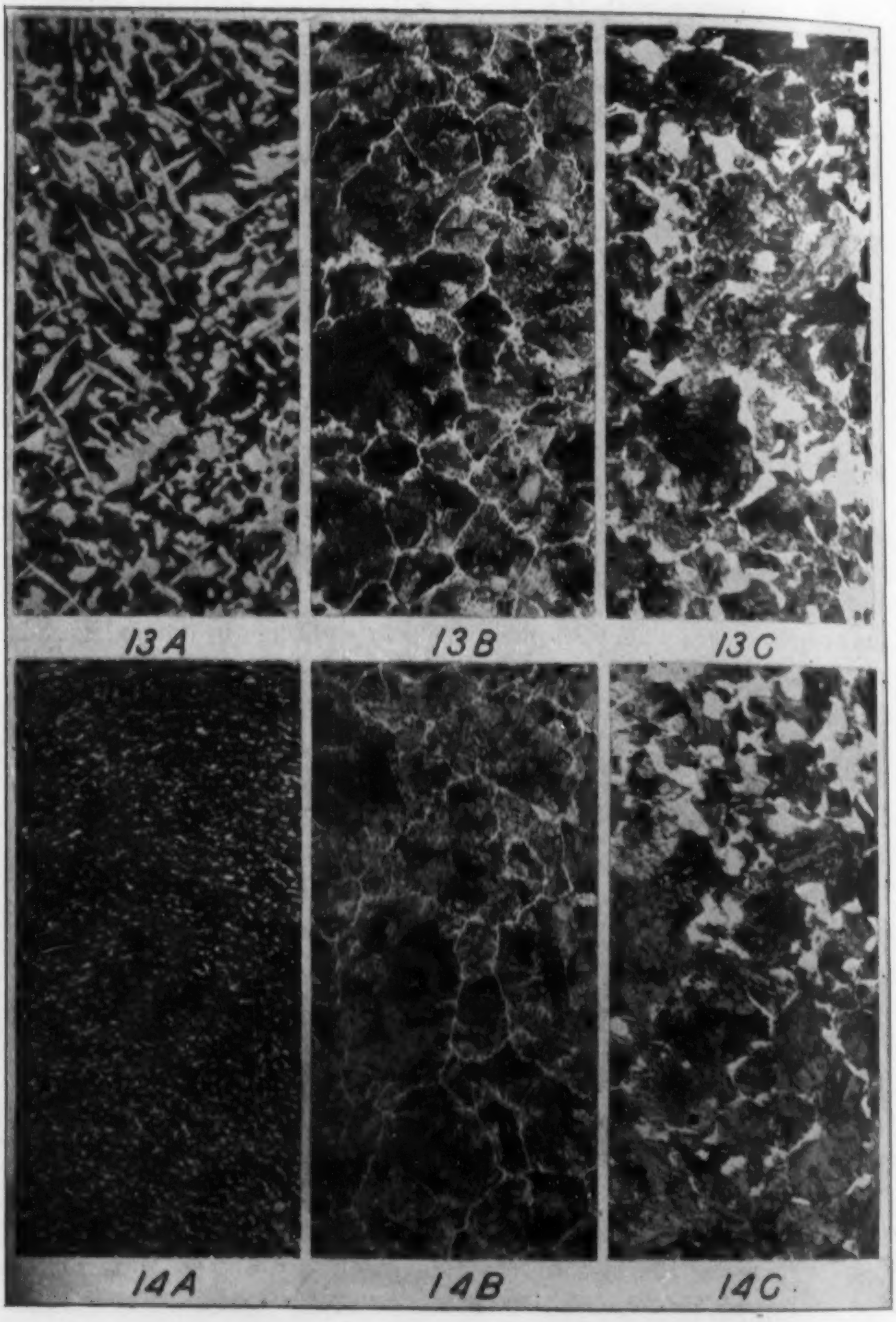
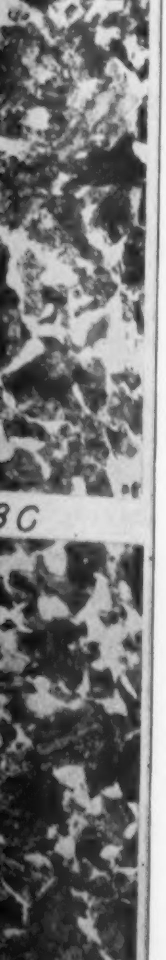


Fig. 13a.—Structure of Steel as Cast. 100x. Fig. 13b—Hypereutectoid Zone of Steel Carburized as Cast. 100x. Fig. 13c—Gradation Zone of Steel Carburized as Cast. 100x. Fig. 14a—Structure of Steel Forged Cold to 1½ Per Cent of the Original Cross-Section. 100x. Fig. 14b—Hypereutectoid Zone of Steel Forged Cold and Carburized at 1725 degrees Fahr. for 6 Hours. 100x. Fig. 14c—Gradation Zone of Steel Forged Cold and Carburized at 1725 degrees Fahr. for 6 Hours. 100x.



d Zone of Steel
as Cast. 100x.
s-Section. 100x.
25 degrees Fahr.
and Carburized

Fig. 15a.—Hypereutectoid Zone of Normal Steel, Normalized at 1600 degrees Fahr. in Air and Carburized at 1725 degrees Fahr. for 6 Hours. 100x. Fig. 15b—Gradation Zone of Normal Steel, Normalized at 1600 degrees Fahr. and Carburized at 1725 degrees Fahr. for 6 Hours. 100x. Fig. 16a—Hypereutectoid Zone of Abnormal Steel, Normalized at 1600 degrees Fahr. and Carburized at 1725 degrees Fahr. for 6 Hours. 100x. Fig. 16b—Gradation Zone of Abnormal Steel, Normalized at 1600 degrees Fahr. and Carburized at 1725 degees Fahr. for 6 Hours. 100x.

Not the slightest digression for the standard pattern could be seen on these samples. The influence of annealing as a factor affecting normality must be, if not entirely disregarded, given only secondary importance.

The problem of establishing the relation between carburizing agents used and the types of cases produced has received a comprehensive study by many able investigators. In the present paper the author has studied only the problem of whether or not cementitic segregations which are often observed in carburized steels are caused by conditions existing in the steel or nonuniformity of distribution of carburizing compound on the surface.

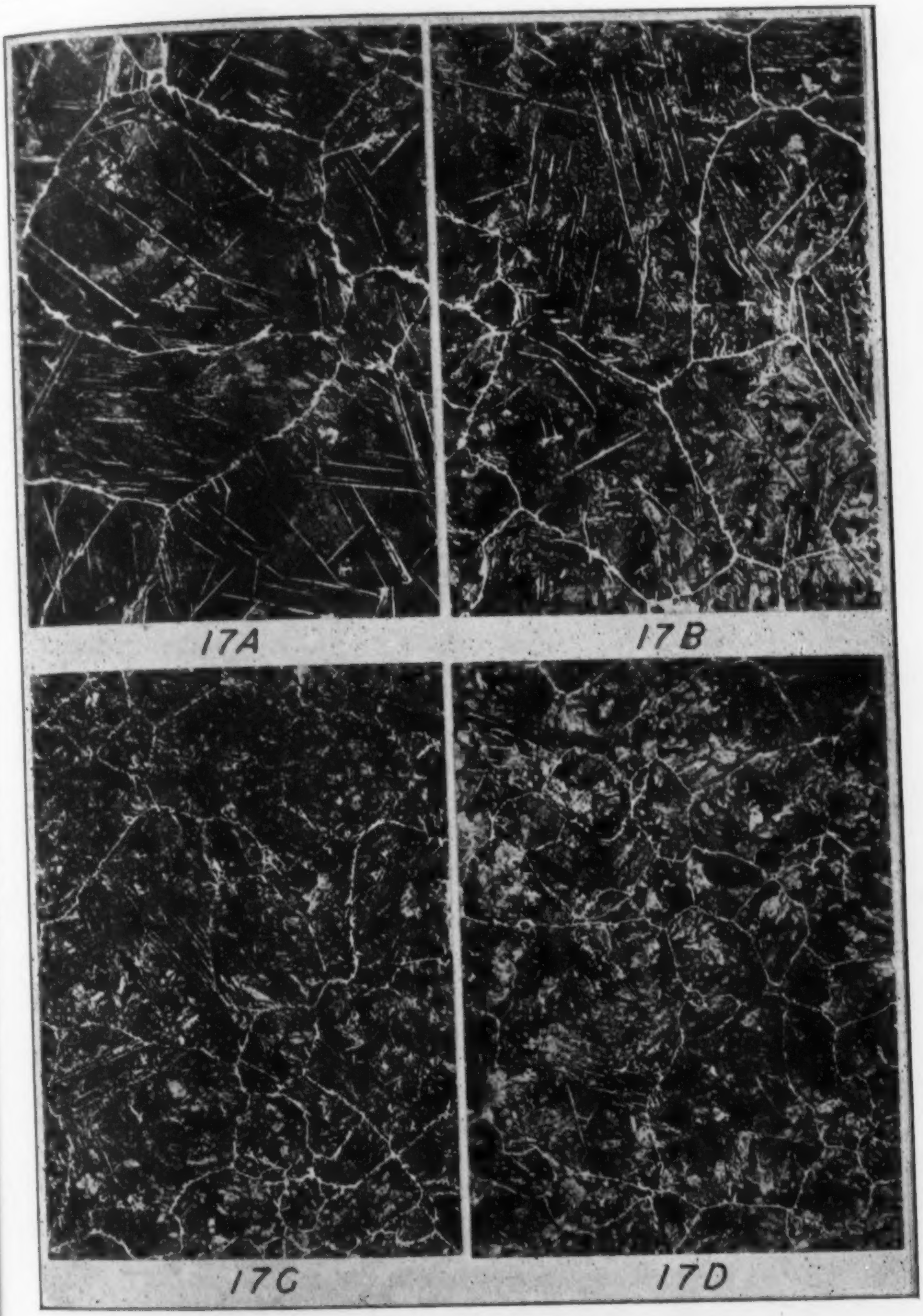
Experimental Procedure

Experimental procedure consisted in heating in a stream of carbon monoxide specimens of polished steel, both normal and abnormal, on the surface of which were placed cylinders of properly prepared sugar charcoal. Time, temperature, rate of gas flow and its pressure were changed one at a time. Carburized surfaces so prepared were examined for carbon distribution.

Neither the polished surface of specimens prepared by cutting these samples longitudinally, nor the slightly polished surface on which the carbon cylinders rested showed any indication of the action of the latter. In the light of these experiments carbon segregations cannot be attributed to unevenness of action of carburizing mixture but rather to conditions present in the steel.

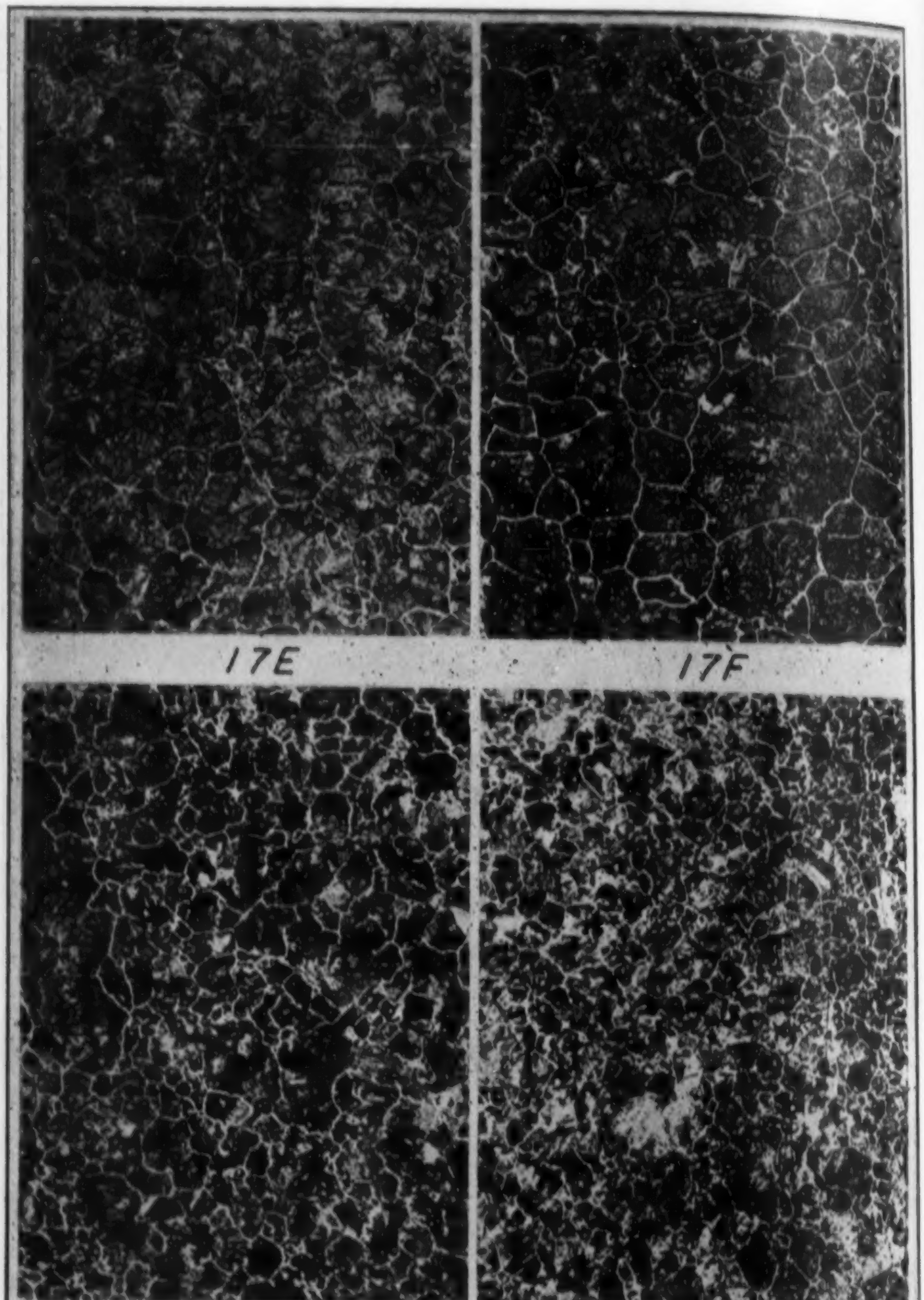
The second property of normal steel, is the production of a uniformly hard case. The problem itself, as to whether abnormal steels produce soft spots on quenching, does not seem to be complicated and could be easily solved by a series of properly conducted quenching experiments. Here, one has only to select specimens representing a continuous chain of them, between totally abnormal and perfectly normal steels and to quench them under conditions warranting uniform and thorough action of the bath. Simple as it appears, the problem is full of difficulties rendering its solution, with the present conception of abnormality, exceedingly complicated.

A grain-size chart represented in Figs. 17a-j, served for a basis of selection, because on a great many occasions it was used as a criterion of normality by steel consumers. After a careful examination a set of specimens was gathered, almost identical in appearance after carburization to ten numbers of the chart. To pre-



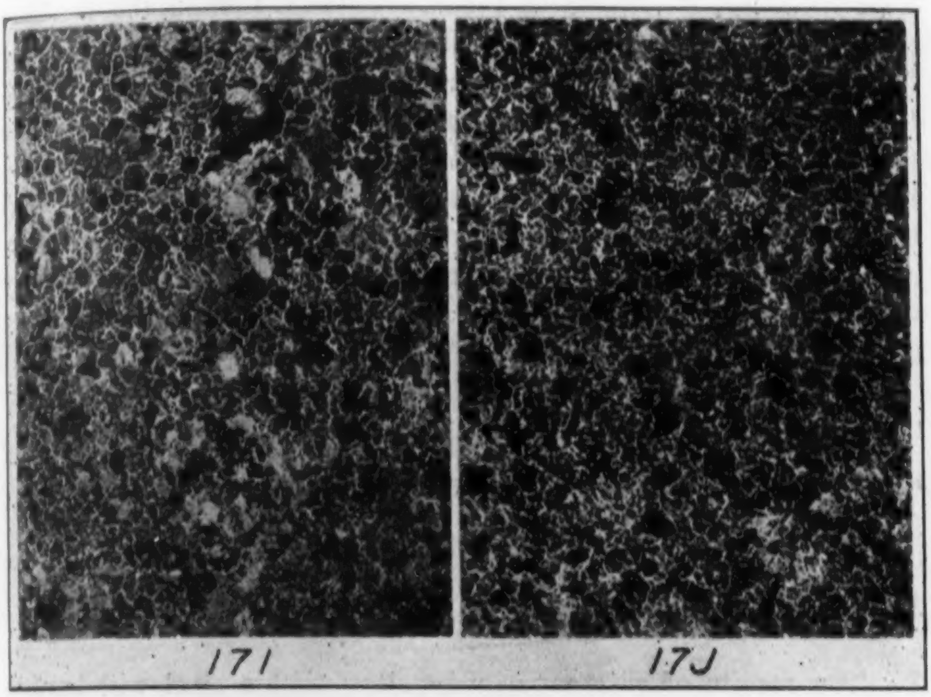
Figs. 17a to 17d—Showing Four Specimens of a "Normality Chart." 100x.

vent interfering action of composition, all of them belonged to the same type, SAE-3115. Hot-rolled bars, $\frac{7}{8}$ inches in diameter, were cut into cylinders about three inches long. The outside and



Figs. 17e to 17h—Showing Four Specimens of "Normality Chart." 100x.

the bases of the bars were polished and carburized in the same box, each type being represented by three cylinders, two of them in the original hot-rolled state, and the third in the normalized



Figs. 17i and 17j—Showing Two Specimens of a "Normality Chart." 100x.

state. The latter was introduced to check the assertion that normalizing before quenching helps the uniformity of hardness.

A sufficient number of specimens were prepared to study two carburizing temperatures and two heat treatments. The first set was kept in a commercial case hardening compound in an electric furnace at 1850 degrees Fahr. for ten hours, the second set for the same length of time but at 1725 degrees Fahr.

After carburizing, the specimens were quenched in water from 1550 degrees Fahr. to refine the core and requenched in water at 1450 degrees Fahr. to refine the case.

Specimens were given a very light polish on Hubert #0 paper and to facilitate the location of possible soft spots, were immersed for a few seconds in dilute hydrochloric acid, so that the difference in coloration could be used as a guide for correct application of the diamond point of the Rockwell tester. Measurements were taken in circles showing a maximum difference in color, at least three such rings being made on each specimen. The distance between impressions was from one to two millimeters. If a circle encountered a well-defined light or dark spot, many impressions

were made on it outside of the main circle, though the readings always were the same.

Data furnished by this series supported previous observations. On all forty specimens no pronounced darkening of the surface was seen, as most of them appeared similar to two represented in Fig. 18, these steels rated at #1 and #10 on the normality chart and were subjected to a double quench, after carburizing at 1725 degrees Fahr. Hardness readings did not show any substantial difference as can be seen from a few representative figures:

1800° F carburized	1550° F quench	1450° F quench	average 65C,	Min 64C, Max 66C
1725° F carburized	1550° F quench	1450° F quench	average 66C,	Min 65C Max 67C
1800° F carburized	1450° F quench		average 65.4C,	Min 64C, Max 66C
1725° F carburized	1450° F quench		average 64.3C,	Min 64C, Max 65C

Results Obtained

The results of this experiment show that a steel will harden satisfactorily if its structure after carburizing is composed of grains of pearlite surrounded by cementitic boundaries. For hardening, the size of the grains of steel is immaterial.

Classifying the large amount of published data pertaining to the description of the appearance of the steel which will not harden satisfactorily, one is attracted by the frequently mentioned reference to "clubbed", "segregated", "divorced" cementite. Though the general meaning of these terms is not difficult to gather, an exact definition is difficult. Looking at the last members of the "normality" series similar to those presented in Fig. 17, one is uncertain whether the areas of cementite as seen at the boundaries of the small pearlitic grains are "clubbed" or not. There is no doubt that in the higher numbers of this series the uniformly thin and even mesh work is broken and that the cementite has segregated in areas larger, sometimes, than the grains of pearlite which it is supposed to surround. The ratio pearlite-cementite is considerably higher here than elsewhere.

On numerous heats examined since the McQuaid-Ehn test made its appearance, cementite appeared as some of the modifications presented on the chart, while in those rare instances when steel would not harden, cementite looked differently, appearing as in

Figs. 5 and 6. Pearlitic grains were surrounded by a thin film of ferrite lying inside of a cementitic mesh. The latter appears as a slightly raised ridge in the middle of a soft ferritic band. The cementitic mesh which is usually observed when examining carburized steels is unmistakeably present and looks much like its

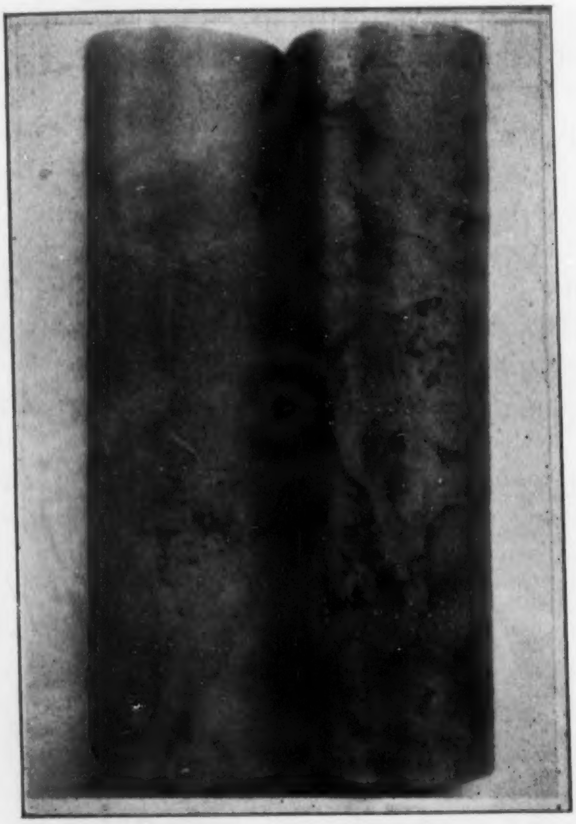


Fig. 18—Soft Spots on Carburized and Hardened Bars of Normal Steel. Natural Size.

normal self. It is thin, well-defined and, seemingly, not much affected by the tendency toward segregation. Should the ferritic lining be omitted, the specimen could easily pass for decidedly "normal" steel with the grain size rating around #4 on the chart just mentioned.

The hardening properties of steel possessing such a structure may be seen from Fig. 19. Specimens taken from it were carburized as usual, lightly polished and etched with a 50 per cent solution of hydrochloric acid. Quenching was conducted accord-

ing to generally adopted practice, from 1425 degrees Fahr. in cold running water. The difference in hardness between martensitic and troostitic areas, easily distinguishable in the photograph, showed an average of 23 points, Rockwell C.

The aim of the present investigation is to point out some of the features inherent to abnormal steel which can be considered as inducive to a given crystallographic appearance, and not to dwell on the subject of crystallization at length.

The first step is the verification of the statement that carbon penetration is greater in large-grained normal steel. Taken literally it conveys an idea that under the same conditions large-grained steel will absorb more carbon than the small grained variety.

Specimens were measured and weighed before and after carburization. The figures so obtained gave amounts of carbon absorbed by the unit of area. These values divided by the depth of case estimated under a microscope furnished carbon concentration in the case.

Nine types of steel were obtained, each of them represented by two heats, selected so that one had a larger grain size than the other. Their composition may be of interest:

	Type	C	Mn	S	P	Si	Cr	Ni	V
1.	SAE 1020	.17	.50	.030	.024	.15	.15	...	..
	SAE 1020	.21	.45	.022	.018	.14	.05	...	..
2.	SAE 2315	.13	.45	.021	.025	.16	.08	3.50	..
	SAE 2315	.14	.50	.025	.015	.17	.06	3.43	..
3.	SAE 2515	.14	.51	.030	.012	.16	.06	4.95	..
	SAE 2515	.15	.63	.023	.016	.10	.10	5.05	..
4.	SAE 3120	.18	.48	.023	.018	.22	.62	1.34	..
	SAE 3120	.19	.60	.030	.016	.20	.65	1.31	..
5.	SAE 5120	.19	.53	.022	.020	.18	.73	...	..
	SAE 5120	.19	.39	.025	.020	.18	.82	.11	..
6.	SAE 6120	.19	.66	.022	.018	.10	1.00	.19	..
	SAE 6120	.19	.71	.018	.017	.18	.90	.19	..
7.	Krupp Analysis ..	.10	.40	.016	.008	.16	1.45	4.00	..
	Krupp Analysis ..	.09	.38	.020	.016	22	1.50	4.14	..
8.	½% Ni	.16	.38	.023	.018	.17	.10	.51	..
	½% Ni	.14	.38	.024	.023	.17	.08	.47	..
9.	Cr-Ni-V	.14	.42	.032	.017	.22	.63	.46	.16
	Cr-Ni-V	.15	.50	.024	.018	.18	.52	.18	.18

Only two different carburizing treatments were studied: Carburization for 6 hours at 1725 degrees Fahr. followed by cooling with the furnace, from 1725 to 1200 degrees Fahr. in three hours and carburization for 6 hours at 1850 degrees Fahr. followed by furnace cooling from 1850 to 1200 degrees Fahr. in four hours.

As stated the total amount of carbon absorbed by a specimen was found as the difference in weight before and after carburiza-

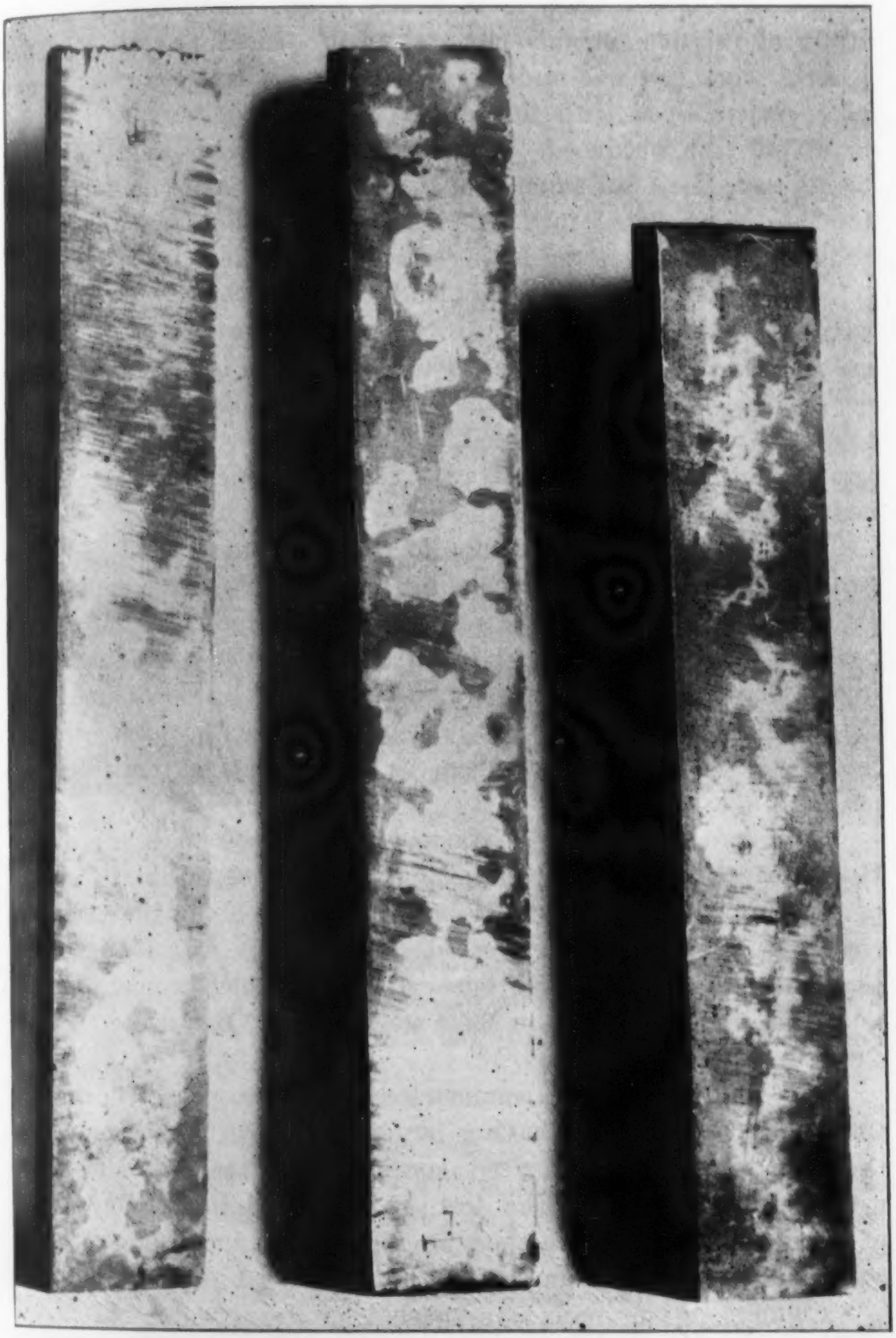


Fig. 19—Carburized, Quenched and Etched Strips of Unhardenable Steel. Natural Size.

tion. This gave a basis from which it was possible to start the study of relative possible penetration of different steels. In the present work this was understood as the ratio between the amount of carbon alloyed with the unit of area of the surface and the depth of case produced. Weighing and micrometrical measurements gave the total amount of carbon alloyed and the surface of the specimen. The depth of the case had to be determined microscopically and was the least certain of the three factors.

After recording the weight and the dimensions, the specimens were split axially and after proper preparation they were placed on the stage of a microscope. The readings, at least nine in number for each specimen, three on each side, (the side on which identification marks were stenciled was omitted) were made by using two sets of verniers of the stage, reading to one-tenth of a millimeter.

Estimation of the thickness of a case is uncertain. Scarcely two observers will agree regarding the imaginary line separating the gradation zone from the core, so that the only solution of the problem, seemingly, could be found by one person taking all readings. The author could always check himself inside of one-tenth of a millimeter selecting as the boundary line the area containing about 0.40 per cent carbon, as it appears in the fully annealed stage.

This procedure was satisfactory in all cases with the exception of steel having the Krupp analysis because the high content of alloying elements made it impossible to obtain the pearlitic structure after cooling as described above. It was thought unjustifiable to cool the whole series at a rate which would produce a pearlitic structure even in these steels, so that they were entirely omitted from consideration.

The following table, summarizes the data obtained in this carburizing series, heats having larger grain size, as judged from the observation of carburized specimens of them produced in a preliminary McQuaid-Ehn test, are recorded in the first place of a given type. The numbers in the first column give an average number of milligrams of carbon absorbed during the test.

Column two presents a somewhat arbitrary value of carbon absorption obtained by the division of the total amount of carbon alloyed with the specimen's surface and the depth of case. Its

SAE	1725° F (940° C) Mgm. C Absorbed	Absorption Value	Depth	1850° F (1010° C) Mgm. C Absorbed	Absorption Value	Depth
1020	134	1.245	1.10	234	1.170	2.00
	136	1.248	1.09	238	1.178	2.00
2315	125	1.250	1.00	221	1.190	1.84
	127	1.233	1.03	216	1.207	1.79
2515	123	1.242	1.99[1]	211	1.116	1.90
	123	1.042	1.18	217	1.107	1.96
3115	132	1.100	1.20	235	1.083	2.17
	133	1.050	1.26	231	1.026	2.25
5120	136	1.162	1.17	238	1.136	2.27
	150	1.154	1.30	242	1.150	2.10
6120	155	1.260	1.23	252	1.211	2.08
	153	1.225	1.25	244	1.162	2.10
Cr-Ni-V	144	1.189	1.21	234	1.187	1.97
	142	1.136	1.25	236	1.098	2.15
½% Ni	133	1.385	.96	240	1.446	1.66
	132	1.434	.96	236	1.493	1.58

[1]Pronounced Banding.

universal acceptance is prevented by the errors encountered in measuring case depth. In column three is given the depth of case expressed in millimeters and representing an average of at least 54 readings.

With the exception of the small-grained specimens of SAE 5120 steel, the first figure of any given class is in close agreement with the second. This is especially interesting as it gives the results of the most accurate of all determinations conducted in the course of this experiment, i.e., weighing of the samples.

In column one the difference seldom reaches 1 per cent, while in column two only in a few occasions does it reach the 3 per cent mark. The depth of case is fairly uniform in both samples, though the differences observed here, both in 1750 and 1850 degrees Fahr. carburization, are more pronounced than in case of increase of weight. This may be partially accounted for by the difficulty of estimation of the case depth, but with the exception of badly banded specimens the deviation in the great majority of cases is under 5 per cent with only one exception Cr-Ni-V heats carburized at 1850 degrees Fahr., where it reaches almost 9 per cent.

With the exception of small-grained specimens of SAE 5120 steel, the peculiar behavior of which is difficult to account for, these figures represent the results which can be expected in commercial practice. Grain size, embracing coagulation of cementite at the grain boundaries, does not affect the dimensions of case produced on it, nor does it affect concentration of the carbon in the outer layers. Steels of the same type absorb under identical conditions an amount of carbon depending on the type of steel only. Carbon

concentration in the case is governed by the type of steel and varies perceptibly from type to type.

To answer the question proposed at the beginning of this series, does grain size affect the characteristics of the case, it was imperative to limit the experimental procedure to steels possessing identical characteristics as far as crystalline structure is concerned. With this point in mind the author used specimens of the same general type, fully killed. This entirely precluded the use of steels, in which traces of split cementite were present, but for checking purposes one set of samples strongly possessing this feature was introduced in the pots containing the main series.

Data showed that the mechanism of carburization of steels belonging to the open class or effervescing type of steel differs considerably from that observed in totally deoxidized metal. As an illustration, a comparison of fully deoxidized SAE 1015 and a special steel[1] are given.

	1725° F (940° C)			1850° F (1010° C)		
SAE 1020	134	1.245	1.10	234	1.170	2.00
Special steel	104	1.155	.90	242	1.180	2.05

Both of these steels can be considered as straight carbon steels. One sample is practically pure iron while the other contains an appreciable quantity of alloying elements so that one may expect a priori that carbon absorption would be governed by composition. Carbon penetration is almost inversely proportional to the carbon content of the steel.

Twenty points difference in carbon cannot by any means increase the speed of carbon penetration, nor could it be inducive to the formation of a heavier case. At the same time practically carbon free metal, having none of the common alloying elements totalling in the case of the samples of SAE 1020 to 1.02 per cent, not only was unequal in carbon absorbing power to the former, but even the case which was formed was almost 20 per cent thinner, on an average. In many occasions the depth of case in the center of the base of the cylinders corresponding to the middle of original ingots, did not exceed one-tenth of a millimeter, but these readings being observed only with the lower carburizing temperature, were not counted in calculating average depth of case, 0.90 millimeter.

[1]Analysis: Carbon 0.02%, Manganese 0.04%, Sulphur 0.023%, Phosphorus 0.006% and Silicon 0.003%.

Carburization at 1850 degrees Fahr. reduced the resistance to carbon penetration, but even in this instance carburization was interfered with to some extent because the amount of carbon absorbed and the depth of case were only slightly better than in steel containing considerably more carbon.

It is not difficult to deduce that the resistance to carbon penetration cannot be a function either of heat treating conditions or analysis as revealed by the usual methods. One is seemingly justified in the assumption that open steels possess a factor influencing their carburization, in its turn affected by the rise of the temperature and probably related to the causes resulting in the phenomenon of split cementite present in open steels which acts as a guide in the pursuit of this factor.

Open or effervescent steels, practically unknown in the alloy steel field, are widely used in the manufacture of sheet steel, being usually of low carbon low alloy stock. Samples taken from 51 heats selected at random in a sheet bar yard were carburized as usual and examined for the above mentioned feature. All of them, except two, showed split cementite, that is, their pearlitic grains were surrounded by free ferrite which in turn surrounded a cementitic mesh. These two exceptions were a high silicon alloy.

The presence of split cementite checked the author's previous experiments. He then proceeded to a normality chart as a check against the orthodox standards. A few specimens taken from the different ranges of the gradual change from very large to quite small crystals shows clearly that the presence of free ferrite is not limited to specific crystalline dimensions. The existence of free ferrite at the boundaries of crystals is unmistakable in all photomicrographs of this series Figs. 20 to 23, covering a sufficient range of grain sizes to be representative. It is true that in Fig. 20 a careful observation is needed to distinguish cementitic ridges in their proper position, while in Fig. 23 they are conspicuous. This point is of utmost importance because it permits the definite separation of the causes leading to the formation of free ferrite from conditions regulating crystallization of the whole mass of the metal. If the splitting of cementite can be seen around crystals approaching in size most ''normal'' specimens of normality charts, interrelation between grain size and ''normality'' becomes decidedly vague, if not misleading. A steel which consists of crys-

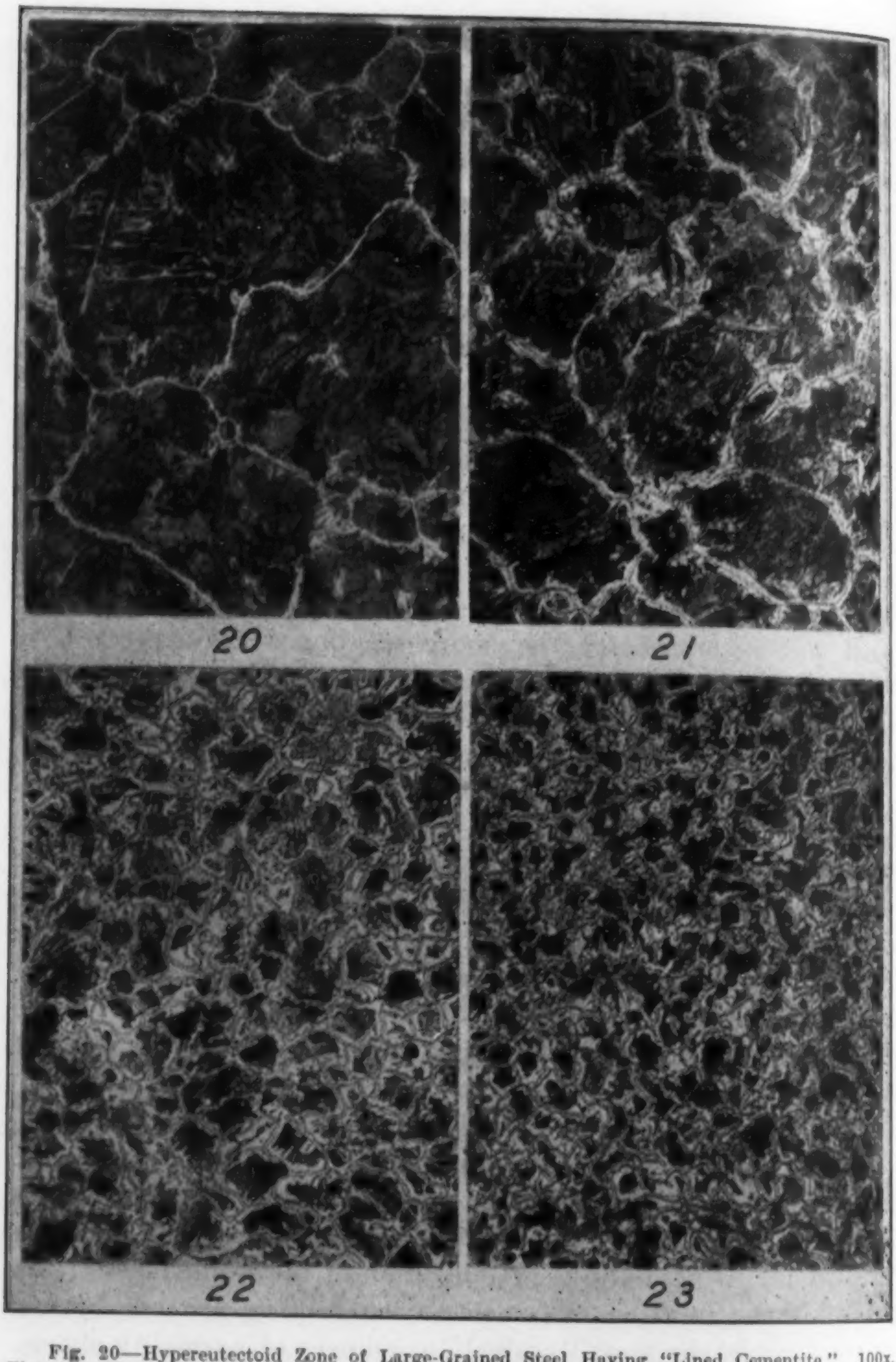
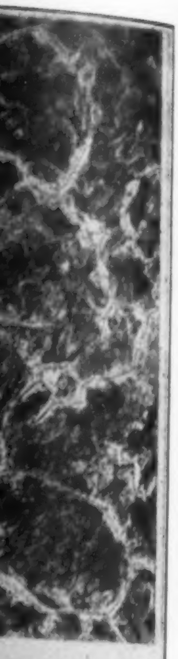
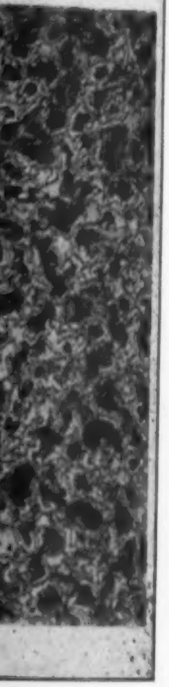


Fig. 20—Hypereutectoid Zone of Large-Grained Steel Having "Lined Cementite." 100x. Fig. 21—Hypereutectoid Zone of Fairly Large-Grained Steel Having "Lined Cementite." 100x. Fig. 22—Hypereutectoid Zone of Medium Large-Grained Steel Having "Lined Cementite." 100x. Fig. 23—Hypereutectoid Zone of Small-Grained Steel Having "Lined Cementite." 100x.





'ementite." 100x.
Lined Cementite."
'Lined Cementite."
Cementite." 100x.

talline units almost discernible with the unaided eye may have this peculiarity while very small grains of some steels similar to Fig. 17j of the normality chart are surrounded by cementite only, segregated as it may be. In other words crystallization of a carburized piece of steel progresses, seemingly, independently of its nature as far as susceptibility to hardening is concerned. On cooling, austenite decomposes into pearlitic grains whose dimensions, depend on factors that are presumably unrelated to the conditions specifying cementitic divorce. Ordinary steel, solidifies as a eutectoid mass enclosed in an already solid cementitic case, resulting in the Ar_1 point on the equilibrium diagram. In a steel having free ferrite around the grains the solidification is more complicated.

At temperatures below the point of cementite precipitation but above Ar_3 the mass filling the cementitic cells is of austenitic character, but probably not true austenite. If austenite is understood to be a solid solution of iron carbide in gamma iron, it is presupposed that the gamma iron after rejection to the grain boundaries of a possible excess of ferrite or cementite above the eutectoid composition, passes bodily into pearlite on passing through the lower critical range. In the present instance a peculiar situation is encountered. The rejection of cementite in a high carbon carburized layer needs no comment, but rejection of excess ferrite following the formation of cementitic cell-work introduces a factor difficult to account for when one starts from the premise that one has the usual austenite inside of the cementitic mesh.

Referring to Figs. 20 to 23, it is not difficult to see that cementite forms in every case a well-outlined mesh, while ferritic bands begin to appear at the beginning as very thin linings along cementitic ridges. They then segregate into more or less massive bodies until at the latest stages practically pure ferritic grains are surrounded by cementite. In every instance ferrite films form receding from the original cementitic mesh toward the inside of a grain.

Elimination of excess carbon in the form of a cementitic film seems to show that at the beginning of transformation, austenite contained more Fe_3C than the amount which could be held in solution at A_{cm}. Either this upsets the present theory of iron-carbon

equilibria, or one must accept the complexity of the original austenite in order to adequately explain the precipitation of ferrite. The first possibility is entirely out of the question.

The visualization of the phenomena taking place on cooling inside of the cementitic mesh work will be considerably simplified. If it be possible to assume that crystals formed after precipitation of cementite consist not of ordinary solution of cementite in gamma iron but form a binary system one component of which is normal austenite and the other austenite containing some third constituent markedly affecting the properties of the alloy. Both components are, presumably, entirely soluble in each other and the solid solution thus produced possesses all the properties of true austenite as long as the temperature does not fall under the upper critical point; just under A_{cm}. The system so produced is subjected, under the critical point, to two distinct sets of transformation, those inherent to binary alloys and the usual allotropic transformations of the iron-carbon system. This point of view is advanced from microscopic evidence. One sees that following normal precipitation of cementite a second substance was precipitated in the interval between A_{cm} and lower critical point.

This deviation from the usual process of transformation suggests that austenite, due, presumably, to the presence of some elements not accounted for in the iron-carbon diagram, is in this case not one solid solution but a combination of two. With the lowering of the temperature, one of them precipitates. It is difficult to attribute this precipitation to cooling alone, because there is always a possibility of different solubility in gamma and alpha iron. Viewed from the first standpoint one may expect to have in the precipitated mass either a definite component of iron with the new constituent, insoluble in the matrix at a given temperature, or a eutectoid composition of all components of austenite with this constituent. The conception of insolubility in allotropic forms of iron cannot materially change the viewpoint on the nature of the rejected compound.

The question whether or not this unidentified (as yet) substance participates in the formation of a cementitic mesh and what is the order of precipitation is answered through the following considerations.

The presence of a cementitic mesh shows that the metal was

saturated with carbon. Assuming the existence of two constituents of austenite it is natural to think that their capacities for holding carbon in solution may be different. On solidification, precipitation of cementite will be regulated by this property of the constituents. With the same carbon-holding capacity independent of the relative percentage of the components, the thickness of the mesh (in its turn proportional to the amount of carbon liberated) will be the same. With the change of their chemical properties the percentage of the constituents will be reflected in the thickness of the mesh. In the case when the constituent which is not transformed into pearlite predominates and is not able to contain on solidification as much carbon as normal austenite, a larger amount of cementite has to be rejected to maintain the equilibrium and a heavier cementitic film will be produced. With the reverse conditions, i. e., with larger absorbent power, the film will be reduced. Examination of Figs. 22 and 23 indicates that this is not the case. While relative amounts of pearlite and structureless constituent vary within wide limits, the thickness of the mesh is practically constant around all grains, some of them consisting of one or the other constituent.

These remarks were made on the assumption that the rejection of cementite followed the formation of structureless compound, but as the deductions were negative it seems that a more solid foundation for the explanation of this phenomena will be in the assumption that the precipitation of cementite precedes the transformation of austenite into its components.

Austenite and Ferrite

The assumption of the existence of a definite constituent of austenite leads to the revision of the term "ferrite," generally used to describe the structureless film interposed between cementite and pearlite in abnormal steel. Scanning the literature reveals few facts or data supporting this point of view. The most frequently used description of this phenomenon (pearlitic divorce), directed minds toward the study of the behavior of two constituents of pearlite. Hypoeutectoid ferrite appeared similar to the constituent in question: rapidly became interchangeable with the latter. It appeared to be free from any crystalline features. Hence the term "ferrite" was applied, although this connection was not rigorously established.

It was assumed that due to the comparatively high difference in resistance to abrasion of ferrite and pearlite one could be scratched while the other would remain intact. A needle scratch across specimens possessing very pronounced films between two

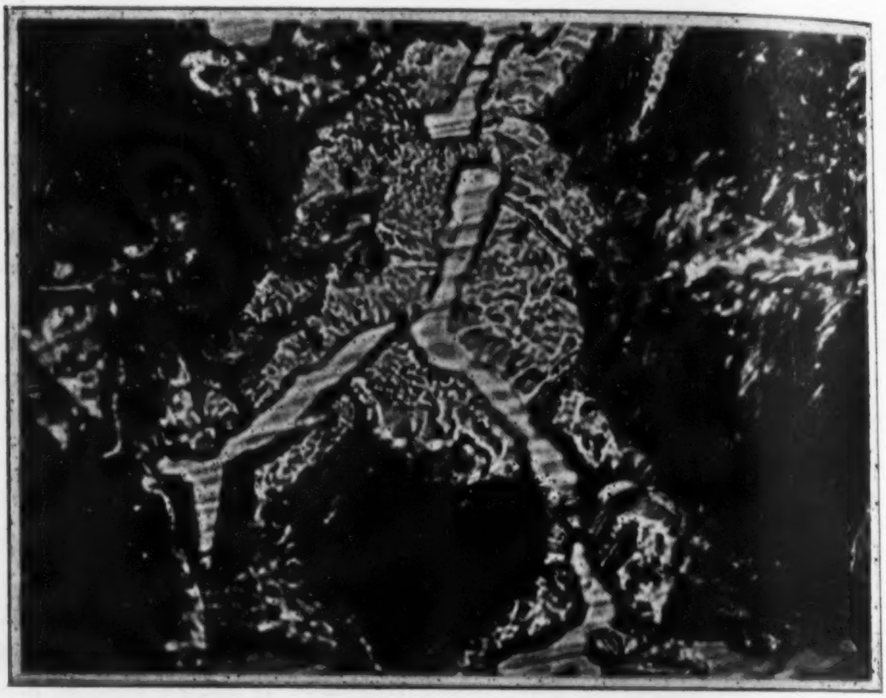


Fig. 24—Eutectoid Alloy Surrounding a Cementitic Mesh in Abnormal Steel. 1500x.

constituents of hypereutectoid zone gave the first indication that the film was not composed of true ferrite. The needle glided on it, but not so perfectly as on cementite, and with no less resistance on the pearlite. If a scratch could be produced it was always observed on the pearlite as well as on these supposedly ferritic films. To make this test more sensitive the ordinary needle was replaced with sharpened wires of different hardnesses, but always lower than the hardness of the needle. This experiment failed to differentiate them. If a scratch were visible it invariably passed through both grains so that it was possible to think that the hardness of the unknown substance and pearlite were of about the same order.

Hypoeutectoid ferrite is not usually endowed with pronounced crystalline characteristics, but low carbon steels show that it is difficult to develop on ferrite any indications of crystal-

line nature other than grain boundaries. Cleavage planes, demonstrated as slip bands, and etching pits are omitted here from consideration as they are developed by means other than ordinary etching. Stronger resistance to etching as compared with pearlite can be held responsible for the fact that in all photomicrographs of abnormal steel found in the literature, such etching was never sufficient to bring out the structure of the films surrounding cementite, being limited by the intensity necessary for full development of pearlite lamellae.

The structure of this film may point to far reaching conclusions. Therefore in preparation of Fig. 24 a considerably stronger etching agent than usual was used to bring out this constituent. Looking at the white mass adjoining a cementitic mesh it is difficult to conclude that one deals with ferrite. Forty seconds immersion in 5 per cent nital failed to develop any grain boundaries. Instead of them there is a pattern of ridges forming an easily discernible mesh work. The structure seems to be somewhat similar to the transitory stages from pearlite to spheroidized cementite but the fact that it is entirely unaffected by sodium picrate opposes this view. It does not possess the properties of any at present known constituents of steel. It is not hard cementite unaffected by acids. Resistance to the action of alkaline ferricyanide and sodium picrate prevents its being a component similar to pearlite or to any of the transitory stages of the latter. Lack of softness eliminates the possibility of it being ferrite, while the presence of a substance of carbidic nature is precluded by the composition[2] of the steel.

Gas Contents

The lamellar structure of the constituent, usually associated with eutectic alloys and its precipitation at the beginning of transformation may give rise to the idea that it is really a eutectoid alloy of iron, carbon and gas, the nature of which has to be established by analysis, but not a definite iron-gas compound similar to oxides or nitrides because their microscopic appearance is too well-known and is quite different from those observed in this case.

Oxygen and hydrogen were determined by means of vacuum fusion and nitrogen by an improved evolution method. A large

[2]Carbon 0.06%, Manganese 0.12%, Sulphur 0.028%, Phosphorus 0.030% and Silicon 0.005%.

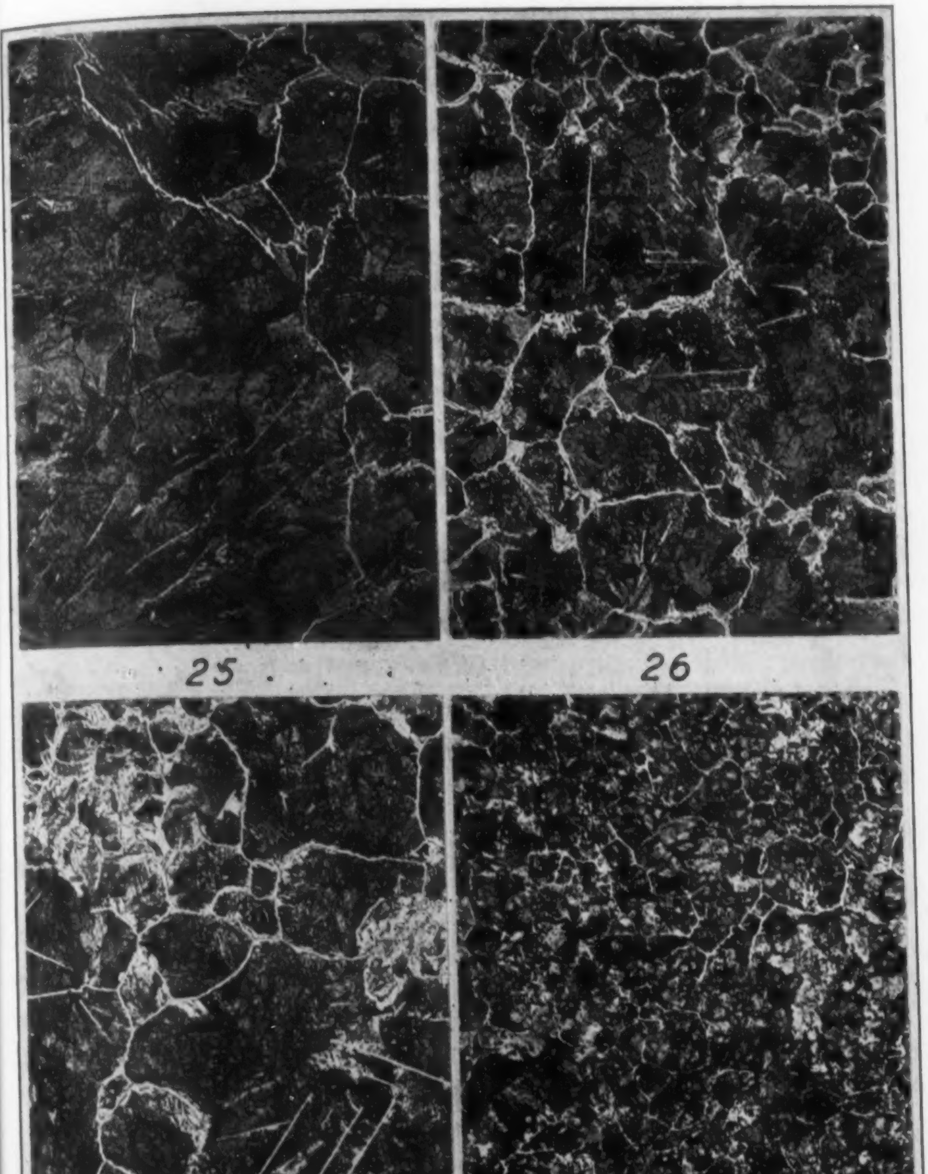
number of determinations was made but their results were so concordant that only a few representative figures are given here

Specimens of different grain size but free from lining of cementite.	Oxygen Per Cent	Nitrogen Per Cent	Hydrogen Per Cent
A	.0051	.0036	.0006
B	.0047	.0032	.0006
C	.0043	.0047	.0009
D	.0066	.0040	.0009
E	.0040	.0037	.0003
F	.0065	.0039	.0003
G	.0055	.0030	.0007
H	.0033	.0068	.0002
I	.0040	.0072	.0004
J	.0034	.0077	.0005
K	.0044	.0070	.0002
Specimens in which eutectoid is present.			
L	.0404	.0028	.0002
M	.0689	.0014	.0008
N	.0531	.0025	.0006
O	.1031	.0039	.0012

Hydrogen and nitrogen seemingly do not have any direct relation to the formation of the eutectoid alloy in question. The oxygen content in steels having a lining of "structureless" substance around the cementite is about ten times higher than in steels lacking it. Neither cementite nor pearlite are capable of holding in solution without changing their properties amounts of oxygen given in the second group of analyses. One does not see any perceptible nonmetallic inclusions like FeO, in any of the constituents of the case, though many in the core. It seems justifiable to think that the amount of oxygen approximately equal to the difference between second and first group figures is carried in these boundaries as rich in oxygen-iron-carbon alloy.

It may be pointed out that steels represented in the second group had a very wide range of grain sizes and a remarkable resistance, after carburization, to uniform hardening under normal quenching conditions. Specimens shown on Fig. 19 were taken from among them. It is interesting to note that quenching in water gave these specimens a difference of hardness in the neighborhood of 23 C Rockwell, but that quenching in brine produced hardness variations within 3 points of Rockwell C. Spots produced after light etching of the hardened surface corresponding to hard and soft areas, were of migratory character as it was shown by repeated (6 cycles) quenchings in water (developing discoloration of the specimens after etching), reheating to the same temperature and quenching in brine, (producing a uniformly-colored surface).

A vivid illustration of the influence of oxygen content on



Figs. 25 to 28—Photomicrographs Taken in a Study of the Oxygen Content in an Open-Hearth Heat During its Making. Fig. 25—Sample Taken when the Charge was Partially Melted. Fig. 26—Sample Taken when the Scrap was Fully Melted. Fig. 27—Sample taken 40 Minutes after Ore Additions. Fig. 28—Sample Taken from the Ladle after all Final Additions were in. Magnifications 100x.

microscopic appearance of steel can be obtained from the study of Figs. 25 to 28 presenting certain steps in an open-hearth heat. It is not difficult to see here first, a comparatively rapid increase of oxygen content, and then a sharp decrease following the addition of deoxidizers. A point of considerable interest, although unrelated to the subject directly, is the influence on grain size of additions to the ladle.

No criterion of normality has been proposed which is definite and understandable to all. The first type of abnormality embraces the shape and size of crystalline constituents of steel to which an arbitrarily selected classification is applied. There is a certain interrelation between three major constituents of a carburized article, hypereutectoid zone, gradation zone and the core so that given characteristic features of one are usually reflected in the appearance of the others. To a given pattern of crystallographic structure are assigned certain properties, especially the tendency for the formation of a uniformly hard case after carburizing and quenching, which is supposed to vary proportionally to the change in variables specifying a given class. Decrease in the grain size and increase of cementite segregated at the grain boundaries is usually considered as inducive to the lowering of carburizing properties of steel.

A second type of abnormality centers on the boundaries between crystalline units of the hypereutectoid zone. As a distinction from the first class it is impossible to connect here crystalline dimensions directly with the microscopic appearance of a specimen as far as the latter can be used as an indicator of normality. At the same time it is clear from a comparison of specimens, that similarly to the first class, there is a certain gradation of normality, though expressed somewhat differently.

A specimen which would rate as perfectly normal in this group is represented by steel having its grains in the hypereutectoid zone surrounded by a mesh of cementite, independently from its size, shape, and freedom from coagulations. Increase of abnormality factors is demonstrated in the transformation of this mesh into a mixture of cementite with eutectoid. The width of the boundaries increases in the same way as the grain size decreases in the first group, i. e., more intensely pronounced abnormality will be associated with heavier boundaries. In the first

stages of abnormality the mesh appears under 100 diameter magnification almost identical to the pattern to which one gets accustomed during the study of the previously mentioned class. Closer observation, especially under higher power, shows that on the verge of a cementitic film there is present a narrow border of eutectoid. It increases until even under 100 diameters of magnification it is easy to see a sharp ridge of imbedded cementite. Still further increase of abnormality changes the thickness of a cementitic ridge. The surrounding eutectoid band increases at the expense of the pearlitic grains until in the worst cases both will be represented by equal areas.

The dimensions of crystalline units cannot be considered as permanent. They are strongly affected by changes in thermal treatment used for the development of easily discernible outlines of grains. Intensification of factors inducing free molecular motion usually magnifies them. Polygonal or rounded grains, surrounded with straight films of cementite serrated, uniform or of widely different sizes is left unaffected by a rise of temperature. The ratio of the amount of cementite present at the grain boundaries and that contained in pearlitic grains decreases in a manner inversely proportional to the temperature.

Mechanical treatment has little if any action on crystalline structure. It results mainly from the necessity for using carburization as the only reliable means for normality determination. Allotropic transformation, necessarily taking place at the temperatures at which carbon penetration can be effected, very strongly interfere with the influence of cold working so that the latter is reduced to mere traces.

In no case was it observed that polygonal grains of "normal" steel act differently than rounded grains of "abnormal" steel. Carbon absorption is identical per unit of area.

With the decrease of grain size the ratio of the amount of cementite present at the grain boundaries to the area of pearlitic crystals increases, provided the observations are made on areas equidistant from the surface, the specimens being of the same shape and the metal free from oxides.

No alloy steels of this type after quenching have any soft areas, not only after a special treatment directed toward their prevention but even after commonly used practice.

The second class of abnormality has been, seemingly, explored even less than the first. It was mentioned above that with the correct practice in the manufacture of deoxidized steels it is almost impossible to find a specimen of metal belonging to the second grouping.

Discussion

Generalizations proposed in the following paragraph are based on personal experience of the author.

The first point of digression from the well-trodden path of previous investigations is the division of ''normality'' into two classes, (1) with the presence of eutectoid alloy and (2) without it. As soon as a parallel set of normality specimens is introduced and steels of the same grain size but surrounded by films of eutectoid alloy are compared with the former, the difference in their physical properties is too pronounced to be overlooked. Charts constructed on grain size alone do not have by themselves any value or interpretation of normality but where explained from the proper standpoint attain properties easily connected with other well-known facts of all the branches of metallurgy.

If one places steels, the crystals of which in the hypereutectoid zone are surrounded by eutectoid layers, beside specimens of the same grain size but free from the films of ferrite they differ in two main points. Quenching after carburizing under normal conditions is usually accompanied by the formation of areas of considerably lower hardness and the warpage observed after similar treatment is usually more pronounced, both phenomena pointing to hindered heat transfer.

The first of these properties was fortunate to receive a comprehensive study in the hands of decidedly practical men as well as of purely scientific workers.[3] All agreed that the prevention of the formation of soft spots consisted or was equivalent to elimination of nonmetallic films on the surface interfering with the proper heat transfer of quenched objects. At least two avenues of approach were recommended, (1) prevention of the action of atmospheric oxygen on the metal when heated before quenching and (2) the instantaneous removal of already formed films by

[3]It is sufficient to mention only the work of W. J. Merten on modification of quenching practice and first and second progress report of the Bureau of Standards on Carburizing.

introduction of some suitable solvent into the quenching bath. In the second case the deductions of the experimenters as far as the possibility of the action of film was concerned were fully supported by the facts observed, the explanation of the reason for the formation of the first one is still forthcoming. In their work nonmetallic films were considered and dealt with as the cause of soft spots, though actually films are the effect of the conditions disclosed in abnormality. The assumption of the oxidic nature of the films was not studied by direct determinations using some sufficiently refined methods.

Experiments were conducted so as to eliminate the influence of all external factors, therefore isolating the influence of abnormality. Their results infallibly show that in abnormal steel there always are present some factors difficult to account for, which tend to render some of the areas more susceptible to the influence of external agents, for example oxidation. A point of considerable interest which is difficult to omit here is the impossibility of attributing this peculiarity to unevenness of distribution of elements, particularly carbon. Repetition of the quenching operation, assuming that the time spent above the critical range was sufficient only for allotropic transformation of iron but too short to allow any perceptible amount of diffusion of possible segregations will not generate soft spots on identical or closely adjoining areas of the carburized surface. Requenching usually results in the formation of troostite in places totally unrelated to the areas on which they were observed previously. Apparently the surface of a heated carburized object made out of abnormal steel is a locale of constantly changing equilibria among numerous physico-chemical factors entering the complicated system represented by a piece of steel under similar conditions. The equilibria are liable to be affected by the outside agents and the resulting phase cannot be expected to be of the same character as those existing at the beginning of the transformation.

This holds equally well for phenomena taking place in both types of steel, but the chief difference is that while in normal steel, equilibria are changing practically simultaneously over the whole surface of a specimen, in abnormal steel, there are present certain conditions which interfere with the propagation of a reaction once it is started. The conditions necessary for supporting

the equilibrium between the metallic system in one place and the external factor, assuming it as permanent, and in an area adjoining it become different and the equilibrium is restored by nonuniform readjustment sometimes involving the formation of a new phase. If this phase happens to be of different heat conductivity than the metal itself the object will respond to the quenching operation showing the peculiarities mentioned above.

The tendency toward the formation of migratory soft spots on quenching gives the first generally intelligible criterion of the quality of a steel. It cannot have two meanings and does not involve any lengthy comments to make it understandable. The limits inside of which hardness readings can vary without placing the specimen in the abnormal class are self-evident.

Heat insulating films dampering the speed of heat transfer on cooling in quenching of abnormal steel are so thin that they are able to decrease the rate of the passage through the critical temperature only to the extent of the formation of the next transformation stage, troostite. Sorbite never has been observed in soft spots. Therefore one has to deal only with two substances and to take into account the hardness of them only. The hardness of martensite may be considered constant. With the rigid quenching, the martensite formed represents rather a eutectoid mixture of alpha and gamma iron carbon alloys and on subsequent tempering its hardness can change somewhat. These changes are very slight and the gradual increase of hardness connected with the decomposition of austenite on tempering is barely discernible with the present methods of hardness testing. On the other hand, transformation of martensite into troostite is connected with a marked drop in hardness easily demonstrated by present apparatus, corresponding to 20-25 points Rockwell C.

Using the tendency for nonuniform hardening as a criterion of quality of steel eliminates attempts to depend entirely on verbal definitions of microscopic appearance as an index of abnormality. If a steel will harden, its appearance must be of a different type than that of an unsatisfactory material because the responsiveness to thermal treatment is too pronouncedly changed not to reflect itself on the structure. The establishing of a true index of abnormality will greatly simplify classification of steels, allowing to account for and to discount factors having only little relation with

normality as being just inherent properties of all steels irrespective of their type.

The dividing line between normality and abnormality, interpreted as a relative ease of uniform hardening, lies, seemingly, in the presence of eutectoid alloy. All other structural peculiarities are connected with grain growth and can be explained on the basis of the theory dealing with this subject.

Advancing a theory radically divergent from generally accepted views on the problem one has to exercise utmost caution. It is impossible to depend on laboratory data no matter how conclusive the evidence may seem to be, how numerous or how elaborate are the experiments. With this idea in mind the author communicated personally with metallurgists of ten leading carburizing plants in the United States, in order to determine whether or not his conclusions were supported by actual experience.

A summation of their opinions undoubtedly reflecting the best tendencies in the art of case hardening of the present time has given a strong support to the views expressed on the preceding pages. The point of maximum interest was naturally the verification of the statement that for hardening purposes steels can be divided into two classes, with the presence of eutectoid alloy and without it. Every one of the persons asked stated unreservedly that steels free from eutectoid alloy, this term was often hidden under some more familiar symbol like "divorced cementite", do not produce any difficulties in hardening, giving uniformly hard surfaces.

Since normality and size of crystalline dimensions are entirely independent qualities it seems to be justifiable to regard the classification of steel on the basis of grain size, valuable as it is for the determination of mechanical properties, as not supported by experimental evidence to be of any value for determination of hardening ability. This statement was made being fully aware of the relations existing between the size of crystalline constituents of a metal and its response to thermal phenomena. It does not cast a shadow on experiments in which utmost refinements in hardening condition permitted comparatively weak influence of grain size to develop itself to a full extent, so that a certain difference in hardness could be observed on entirely normal steels.

There are undoubtedly some valid reasons why a steel crystal-

lizes in some cases give a decidedly polygonal appearance, in others are rounded or enclosed in a mesh of serrated cementite, or why in one case crystalline dimensions are uniform while in another a wide difference can easily be seen. These questions fall into the realm of crystallization and grain growth similar to all steels, independently of their state of normality, a subject of too great a magnitude to be attempted to be handled in a comparatively short paper intended to bring out the properties of steel inducive to hardening defects.

If one does not see clearly the reasons for the formation of any definite type of crystalline pattern, some other crystalline transformations can be comparatively easily explained based on generally accepted premises. The tendency of small-grained steel to germinate in the gradation zone is not unrelated to the general trend in this direction of all small-grained material. Removal of cementitic segregations at the grain boundaries of small-grained steels and the enlargement of crystalline units of the latter with the rise of temperature is in good accord with laws of carburization, formulated from work of the authors cited above, and connected with greater molecular mobility. Impeded grain growth in high carbon steels as well as the difficulty of carbon penetration at lower temperatures is probably inhibited by the action of carbon atoms in the space lattice of steel which act as keys for molecular arrangement. Migration of carbon along grain boundaries and decreasing carbon-holding capacity at lower temperatures seem to account for cementitic segregations in the outer zones of small-grained steels carburized at low temperatures.

Experiments illustrating this paper were conducted on rich in oxygen steels or on entirely deoxidized metal, eliminating therefore from consideration the class of steels which has given rise to the conception of abnormality, incompletely deoxidized metal. If there is no difficulty in drawing the demarkation line between the properties of steels differing in tenfold gas content, one is at a loss to specify how much oxygen a metal can contain without acquiring properties of antihardening steel. The range at the border of these two classes possessing the features inherent to ordinary crystallization as well as those caused by excessive oxygen content lead to most difficulties in the interpretation of the appearance of carburized specimens due to difficulties connected

with the separation of features stipulating resistance to hardening from those created by conditions of inherent crystallization to a given steel and not directly connected with the amount of oxygen present.

Analytical determination of oxygen especially by the vacuum fusion method is liable to furnish in this range, where differences involved are small, somewhat misleading results, because it does not separate between the gas available for the formation of eutectoid alloy and tied up in difficultly reducible oxides of alumina, silicon, etc. A steel containing a large amount of nonmetallic inclusions may show even a greater percentage of oxygen than one free from them though the latter may produce a eutectoid lining of cementite, while the former will harden without any defects.

The carburizing test is free from this limitation and, though the intermediate range is still open for a most interesting study in regard to the permissible amount of oxygen, a steel may be considered as possessing proper hardening qualities if after carburization pearlitic grains of it are surrounded by cementite free from intermediate layer of eutectoid alloy, disregarding all other conditions.

The author wishes to acknowledge his deep gratitude to G. W. Gable for his untiring help in preparation of the material for this paper.

GENERAL DISCUSSION

Written Discussion: By G. R. Brophy, Schenectady, N. Y. The information contained in this splendid paper pertaining to the gas dissolved in quenching baths is of particular interest to the writer who has been working along this line for some time past. The work of Dr. Benedick's on the "Hot Wall Action as a Factor in the Rapid Corrosion of Boiler Tubes" indicated the real cause of the so-called "fugitive" soft spots which form on the surface of steel when quenched in water.

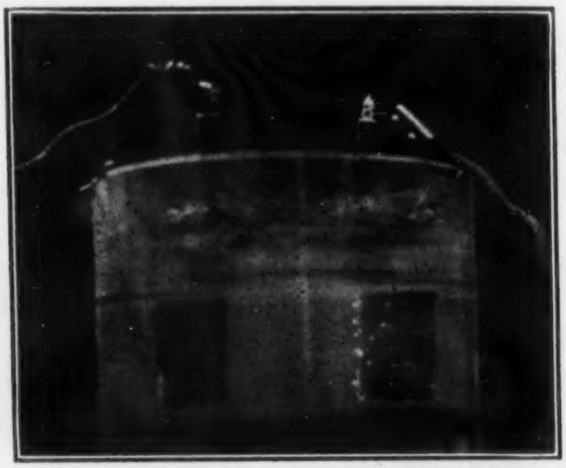
The work done in this laboratory consisted of two parts (1) studying the relation of dissolved gas to soft spots and (2) the effect of the surface finish on gas and steam deposition and retention on surfaces of steel heated in water.

Cylindrical specimens of 0.80 carbon steel ¾ inch in diameter and two inches long were prepared for quenching experiments. Surfaces of same were finely ground previous to hardening and others were knurled to give a rough surface. These were quenched in tap water, brine, and water which had been boiled and cooled in partial vacuum.

The smooth surface cylinders in all cases had fewer soft spots than

those with knurled surfaces. Knurled surfaces quenched in tap water varied in hardness from C-42 to C-64, while brine and boiled water gave more uniform results at 60-66. A few readings at 69 were obtained on brine quenching. Smooth surfaces quenched in brine and water varied only between 64-66.

The condition of the surface effects the retention of gas on the surface as is demonstrated in the following experiment. Hollow, thin-walled, cylinders were immersed in the three baths mentioned, and heated by inserted series resistance coils. In tap water bubbles form on the surfaces as soon as heating begins but are liberated at once from the polished surface. On the rough surface they cling so tenaciously that they can be dislodged only with difficulty when wiped, and agitating the bath does not remove them. (See photograph).



Polished Surface—Left. Knurled Surface—Right.

In brine and boiled water the number of air bubbles is materially reduced.

Temperature measurements were made on the surfaces of the immersed specimen and the rough surface was found to run 10 degrees higher than the smooth. This is probably due to the insulating effect of the gas collected there. The heating coils were interchanged and the readings checked. In freshly prepared brine no temperature difference could be determined under the same conditions.

Samples which were immersed for several hours and had collected a permanent crop of bubbles showed remarkable pitting under each bubble and relatively no attack in other areas. This agrees with Benedick's observations on the corrosion of boiler tubes.

We have found, therefore, the Ludwig-Soret effect occurring in the heat treatment of steel as well as in its manufacture, as pointed out by Benedicks.

From these experiments and those of the authors, we must attribute fugitive soft spots to the insulating effect of gases (and steam) which

are drawn from the quenching bath and deposited on the surface of the steel quenched. The reason little or no gas is obtained from a freshly prepared brine solution is that the salt when dissolving in water lowers the solubility of the gas and thus liberates it. This action can be easily seen and needs no further proof.

Written Discussion: By G. V. Luerssen, Reading, Pa. The authors are to be commended upon the broad manner in which they have regarded the relative merits of normal and abnormal steels. The laboratory with which the writer is connected has conducted extensive work upon this subject covering the past four years, largely upon tool steels. We have checked in practically every detail, the experimental results obtained by the authors, and have arrived at the same general conclusion, i. e., with regard to the relative suitability of normal and abnormal steel viz., that the degree of normality desired depends largely upon the particular purpose for which the steel is to be used.

The term "normality" is thus rather unfortunate, and care must be taken in interpreting results to consider normality as a reaction obtained by applying the McQuaid-Ehn carburizing test and not as a criterion of general tool steel quality.

Written Discussion: By G. L. Kelley, Philadelphia. The authors McQuaid and Ehn on the irregularities encountered in the carburization of steel have caused a great deal of interesting discussion. Many metallurgists were at first sceptical as to their findings. This impression has since given way to a feeling that these authors have made an exceedingly valuable observation. It will doubtless require much investigative effort to clear up all of the points suggested by their work, but the present report of progress from the Bureau of Standards by Epstein and Rawdon appears to establish certain relations among some of the phenomena.

Epstein and Rawdon find that the oxygen content as determined by the vacuum fusion method bears no relation to the "normality" or "abnormality" of steel, while J. D. Gat in his paper seems to reach an exactly opposite conclusion. This disagreement will need to be resolved by further work. Much interest attaches to observations by Epstein and Rawdon on the effect on hardening produced by gases in the water used for quenching and in the success which attends hardening either normal or abnormal steel in brine or sodium hydroxide solutions. Of especial importance are the comparative results obtained by killing the steel in the ladle and in the mold with the deoxidizing agents aluminum, ferrovanadium and ferrosilicon. If this is confirmed in practice, it will be possible to so control the manufacture as to produce at will either normal or abnormal steel.

It is a pleasure to take this occasion to say that the authors have set forth their findings in a very clear and interesting manner.

Written Discussion: By G. F. Comstock, Niagara Falls, N. Y.

Although J. D. Gat in his paper has brought forward a very interesting theory in regard to the basic cause of what is generally known as "abnormality" of steel, it is unfortunate that he has not followed ordinary usage in the application of the metallographic terms chosen to describe

the structures that he has seen. The term "eutectoid" for instance is used carelessly in most of the paper. On page 380, lines 7 and 9, this term is given its proper meaning as applied to pearlite, and most metallographists in seeing this term used in relation to steel, think at once of pearlite. Without further specific information, the table at the top of page 404 might be taken to imply that no network of cementite, or pearlite (the real eutectoid in steel) was present in samples A to K, while samples L to O contained pearlite. In connection with page 411, lines 21 to 22, one wonders if the author really means a steel free from pearlite in suggesting one without eutectoid alloy? This confusion occurs also on page 379, line 7, and at many other parts of the paper. Near the middle of page 410, martensite seems to be called a "eutectoid" also. Other terms that are not at all clear are: "split cementite" (is this the same as the free ferrite mentioned on page 397, lines 28?), "cementitic divorce", "lining of a cementitic mesh", and "eutectoid lining of cementite." The writer can hardly believe that many readers of the TRANSACTIONS really understand just what the author means by these terms, and whether they all mean the same thing or not. The paper would certainly receive more serious attention if the language used was more clear.

Most of the photomicrographs presented are excellent, but Fig. 24 is very weak support for the author's theory. Overetched ferrite nearly always has the appearance shown there, and ferrite not polished well may have the same appearance even when not overetched. The resistance of the ferrite to scratching, as mentioned by the author, was probably due to the thinness of the ferrite film. He should use as a check on these deductions regarding the scratch-hardness of ferrite, not a soft steel containing large ferrite areas, but a pearlitic steel with very little free ferrite between the grains. Probably such thin bands of ferrite would not be scratched very much easier than the pearlite. The author's oxygen determinations are really the only support of much value for his theory of an "oxygen-iron-carbon alloy" in abnormal steel.

Oral Discussion

W. J. MERTEN: I have read and listened with a great deal of interest to what the authors had to say in their report. They start out declaring avoidance of theoretical speculation. Before they are half finished, two theories of abnormality are inducted—that of "grain size" and "structural" abnormality. They find, however, that neither can be measured definitely by soft spots or irregularity of surface hardness. The authors also state that fully hard and uniformly hard surfaces can be obtained on abnormal steel by drastic quenching. This statement interpreted rightly points out that uniform hardness depends upon surface conditions of the steel and not upon structural composition nor structural uniformity. It seems to me that soft spots can well be explained by considering that a small irregular grain of so-called abnormal steel presents a surface condition during rapid cooling by quenching, which retains more readily the vapors formed than a surface with large network cementite grains (normal structure).

Then quenching in liquids in which lime is suspended will produce uniformly hard surfaces of both normal and abnormal structures, which is proven. Furthermore there is apparently no evidence that fine grained abnormal structures do not wear even better than a normal structure providing both are uniformly hard.

Aside from this, I would like to introduce into this discussion the results of an investigation conducted by E. C. Smith and Mr. Morris of the Central Steel Company, to show that structural abnormality is not inherent and can be introduced by selective straining. This obviously confirms my statements and observations reported in my paper in Cleveland in 1925.

THE RELATION BETWEEN STRAIN AND CARBURIZING

Purpose. The purpose of this investigation was to determine the effect of strain upon the subsequent carburizing of the strained material.

Material Used. For this investigation sections of low carbon, plain carbon strip steel (approximately one inch wide and 0.205 inch thick) of the following analysis were used.

	Per Cent
Carbon	0.08 to 0.12
Manganese	0.35 to 0.50
Sulphur	0.04
Phosphorus	0.04

Experiments. Eighteen samples of the strip were bent in the shape of a U and given the following treatments. Six samples were used for each treatment.

Experiment A. The samples were annealed at 700 degrees Cent. (1292 degrees Fahr.) for 8 hours and furnace cooled. The samples were then given a standard carburizing test which consisted of carburizing the samples for 8 hours at 1690 degrees Fahr. and furnace cooling. The purpose of this experiment was to produce coarse grains prior to carburizing.

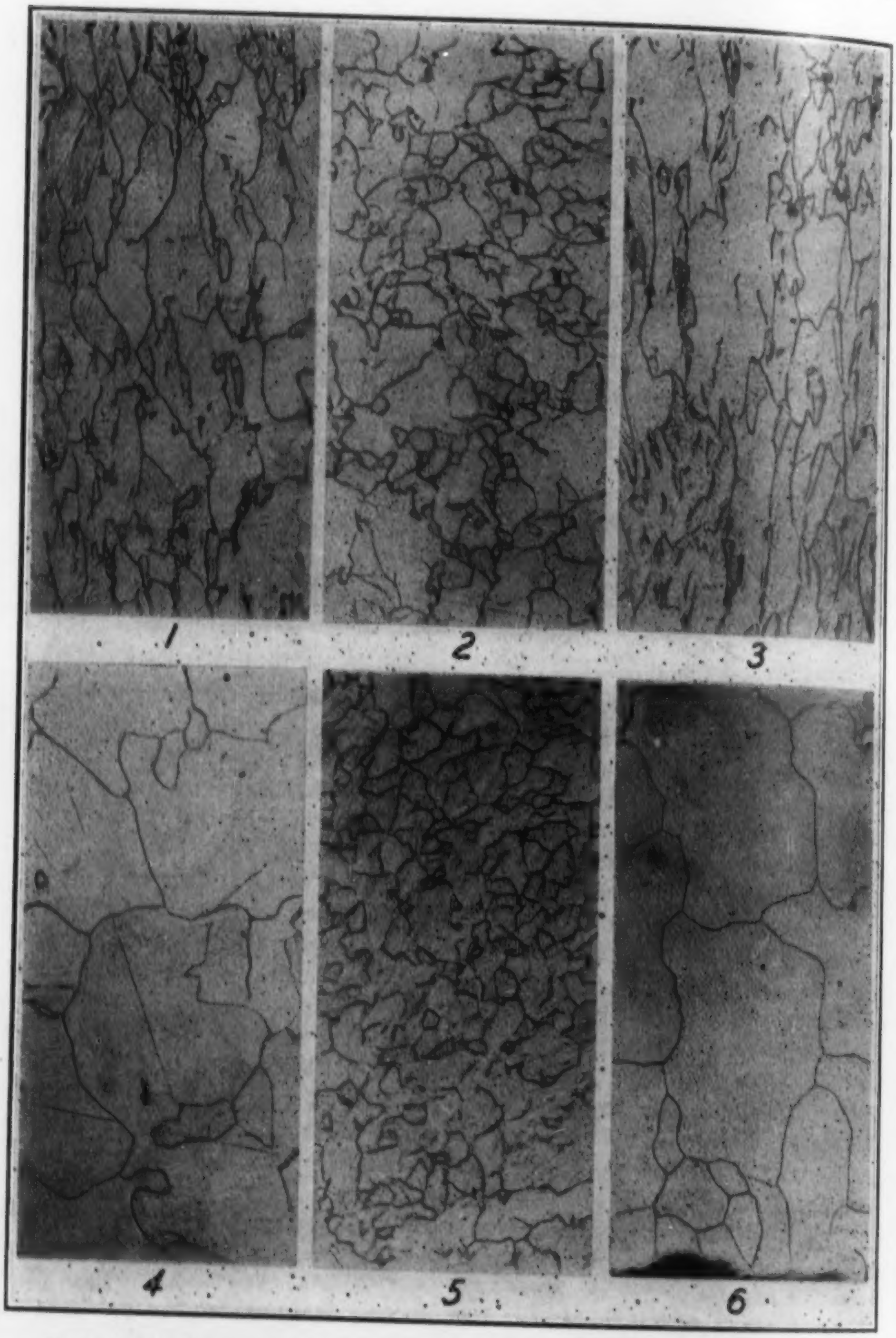
Experiment B. The samples were normalized at 1650 degrees Fahr. for 15 minutes and then given a standard carburizing test as in Experiment A.

The purpose of this experiment was to remove the strain before carburizing the samples in order to see what effect the removal of the strain would have upon the subsequent carburizing.

Experiment C. The samples in this experiment were heated to 700 degrees Cent. (1292 degrees Fahr.) held for 7 hours and then heated to 1690 degrees Fahr. and held for 8 hours, after which the samples were furnace cooled. The purpose of this experiment was to determine what effect a slow or delayed heating to the carburizing temperature would have upon the subsequent carburizing.

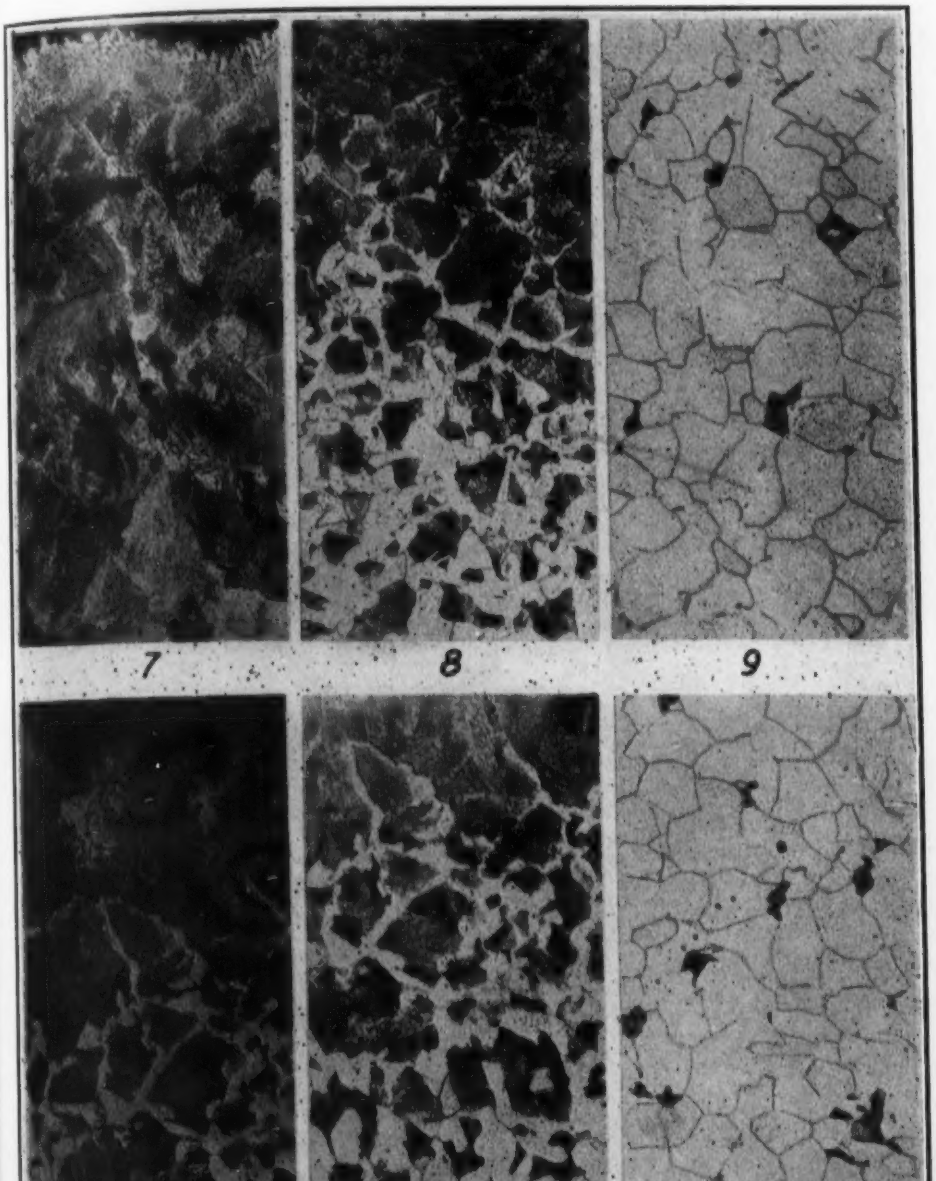
Microanalysis. For microanalysis the samples were cut in half, one half being polished for examination. This gave a fresh surface well underneath the case.

Experiment A. The samples of this experiment at the tip of the bend on the outside and directly underneath the tip on the inside showed no hypereutectoid zone, that is, the case at these two points is not supersaturated with respect to cementite. The case at these two points is also thinner than that of the unstrained parts of the sample. The unstrained parts of the sample both

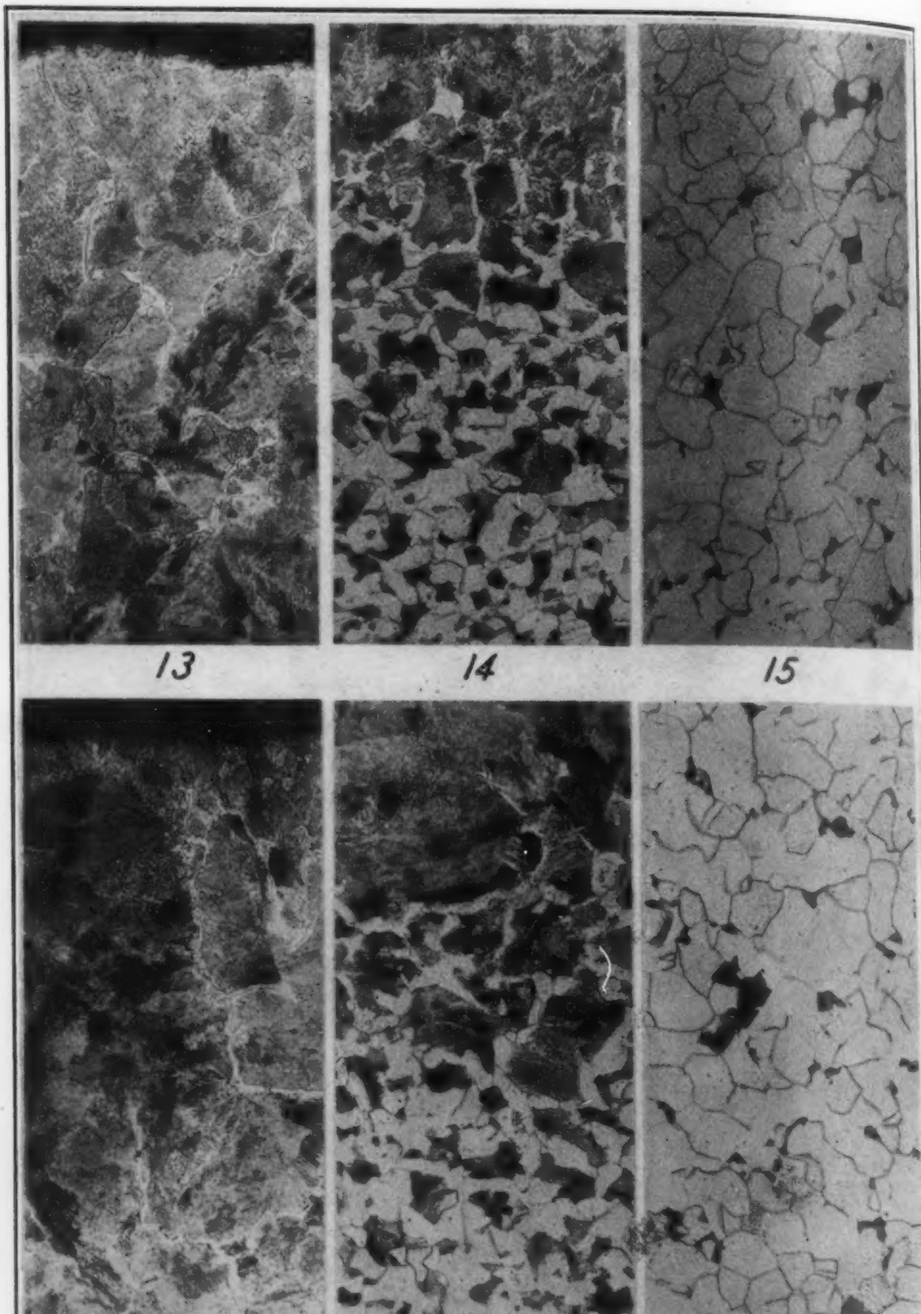


Photomicrographs of Samples as Rolled and Bent. Fig. 1—Outside of Bend at Tip. Fig. 2—Midway Between Outside and Inside. Fig. 3—Inside of Bend Underneath Tip. Photomicrographs of Samples from Experiment A. These Samples were Annealed Only. Fig. 4—Outside of Bend at Tip Showing Grain Growth. Fig. 5—Midway Between Outside and Inside. Fig. 6—Inside of Bend Underneath Tip. All Samples Etched with Nitric Acid. Magnification 100 x.

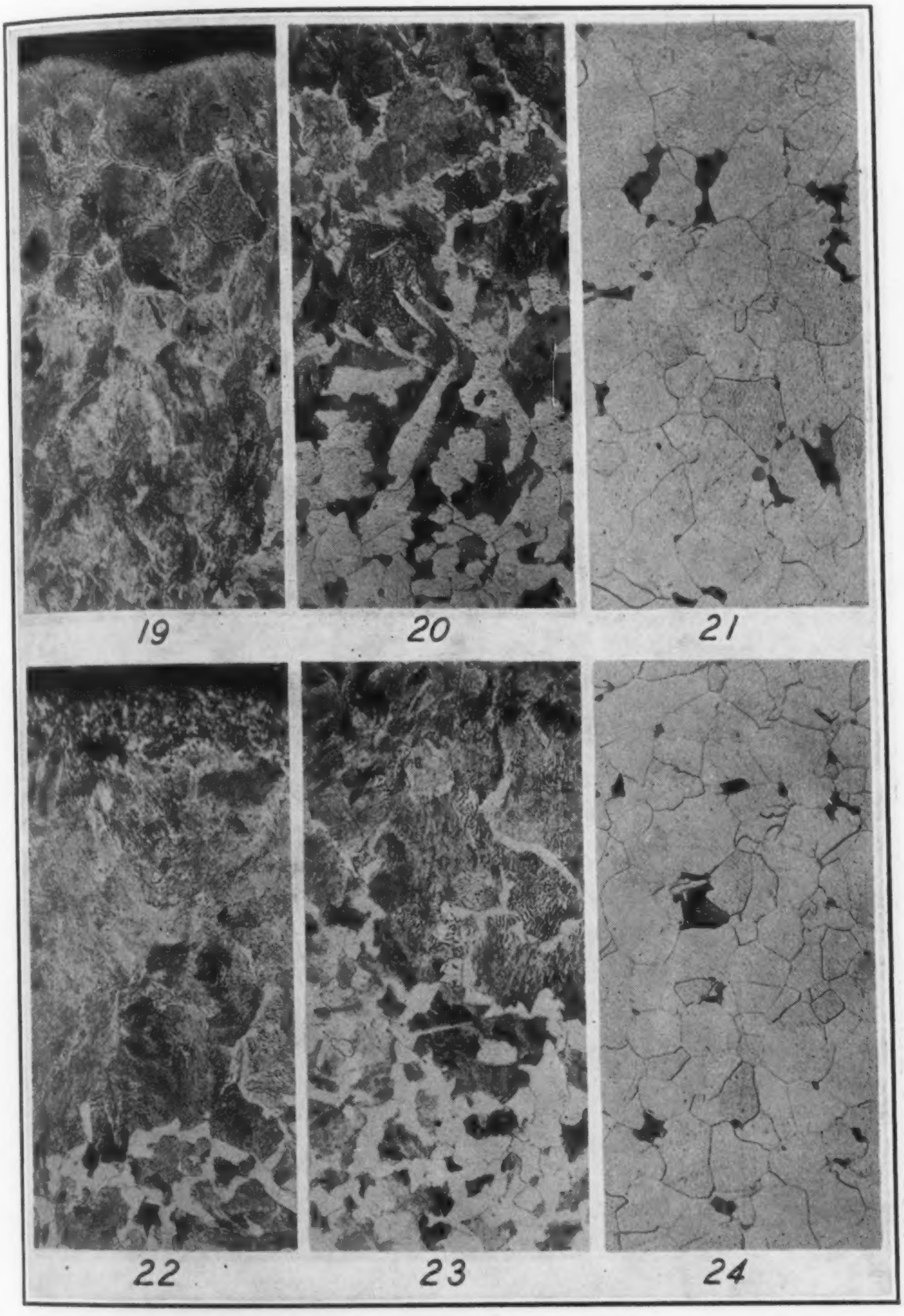
Bend at Tip. Fig. 2
h Tip. Photomicro-
y. Fig. 4—Outside
nd Inside. Fig. 6—
Magnification 100 x.



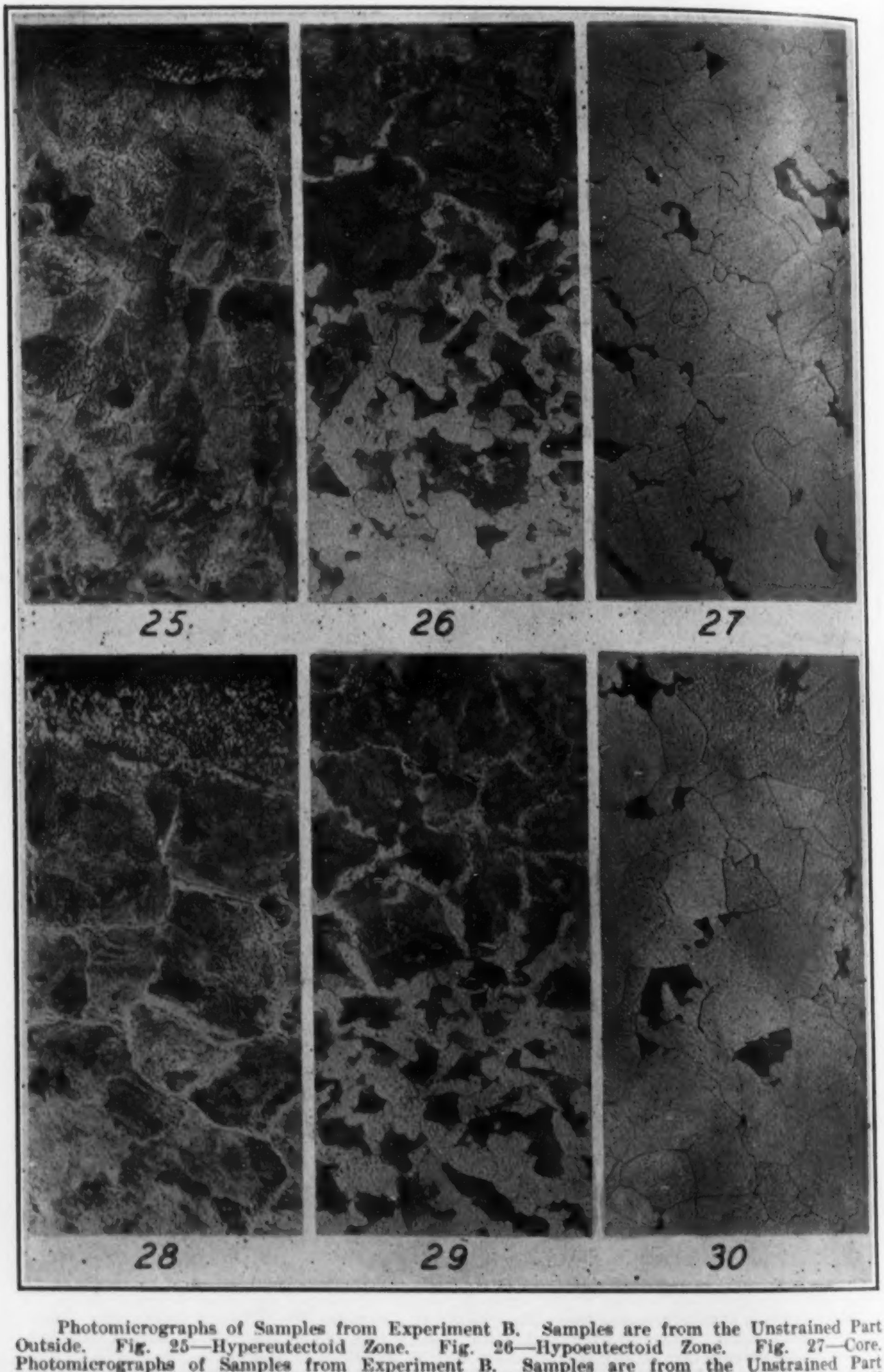
Photomicrographs of Sample from Experiment A at Tip of Bend. Fig. 7—Hypereutectoid Zone. Fig. 8—Hypoeutectoid Zone. Fig. 9—Core. Photomicrographs of Samples from Experiment A. Samples Taken from Inside of Bend Underneath Tip. Fig. 10—Hypereutectoid Zone. Fig. 11—Hypoeutectoid Zone. Fig. 12—Core. All Samples Etched with Nitric Acid. Magnification 100 x.



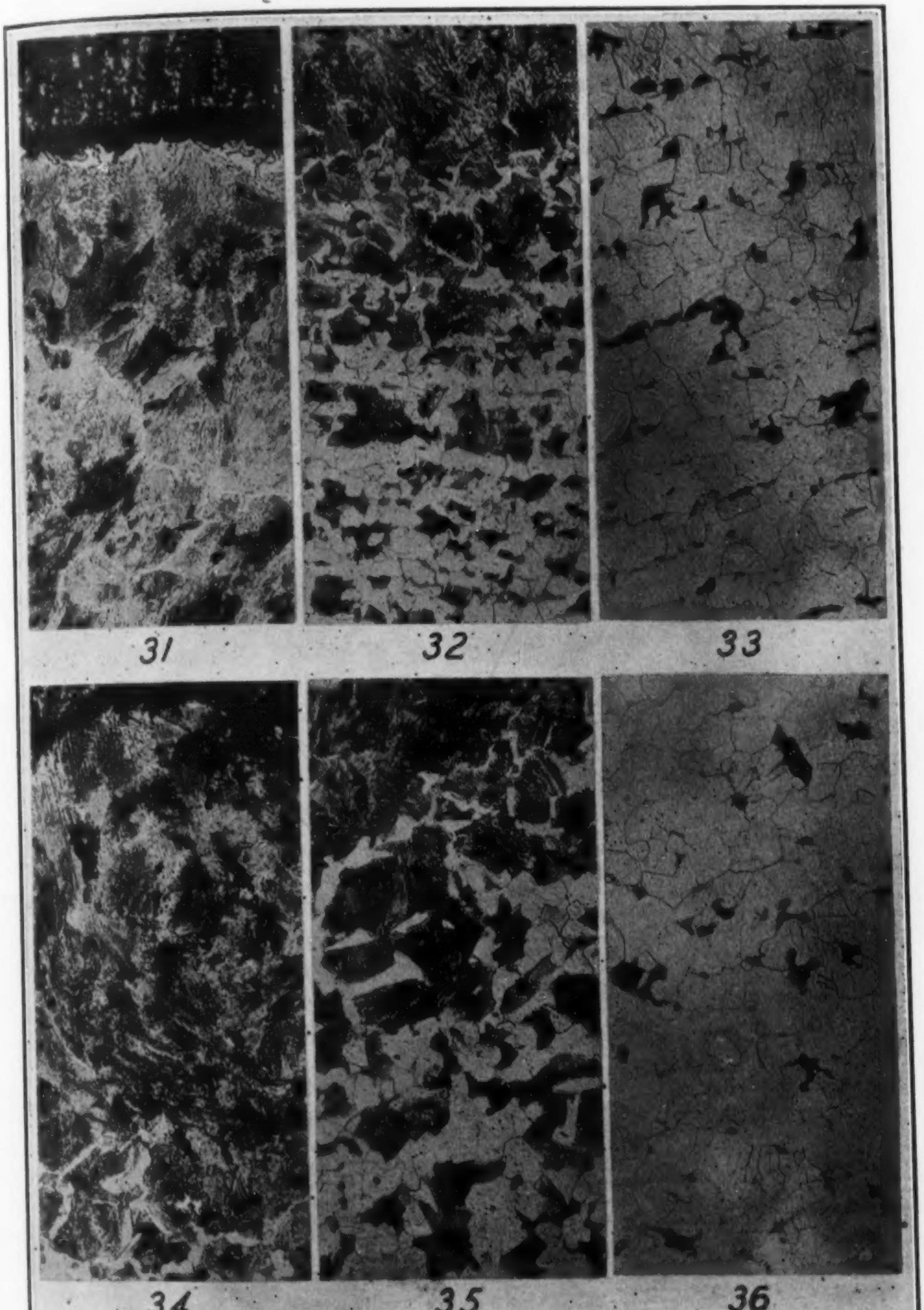
Photomicrographs of Samples from Experiment A. Samples are from the Unstrained Part Outside. Fig. 13—Hypereutectoid Zone. Fig. 14—Hypoeutectoid Zone. Fig. 15—Core. Photomicrographs of Samples from Experiment A. Samples from Unstrained Part Inside. Fig. 16—Hypereutectoid Zone. Fig. 17—Hypoeutectoid Zone. Fig. 18—Core. All Samples Etched with Nitric Acid. Magnification 100 x.



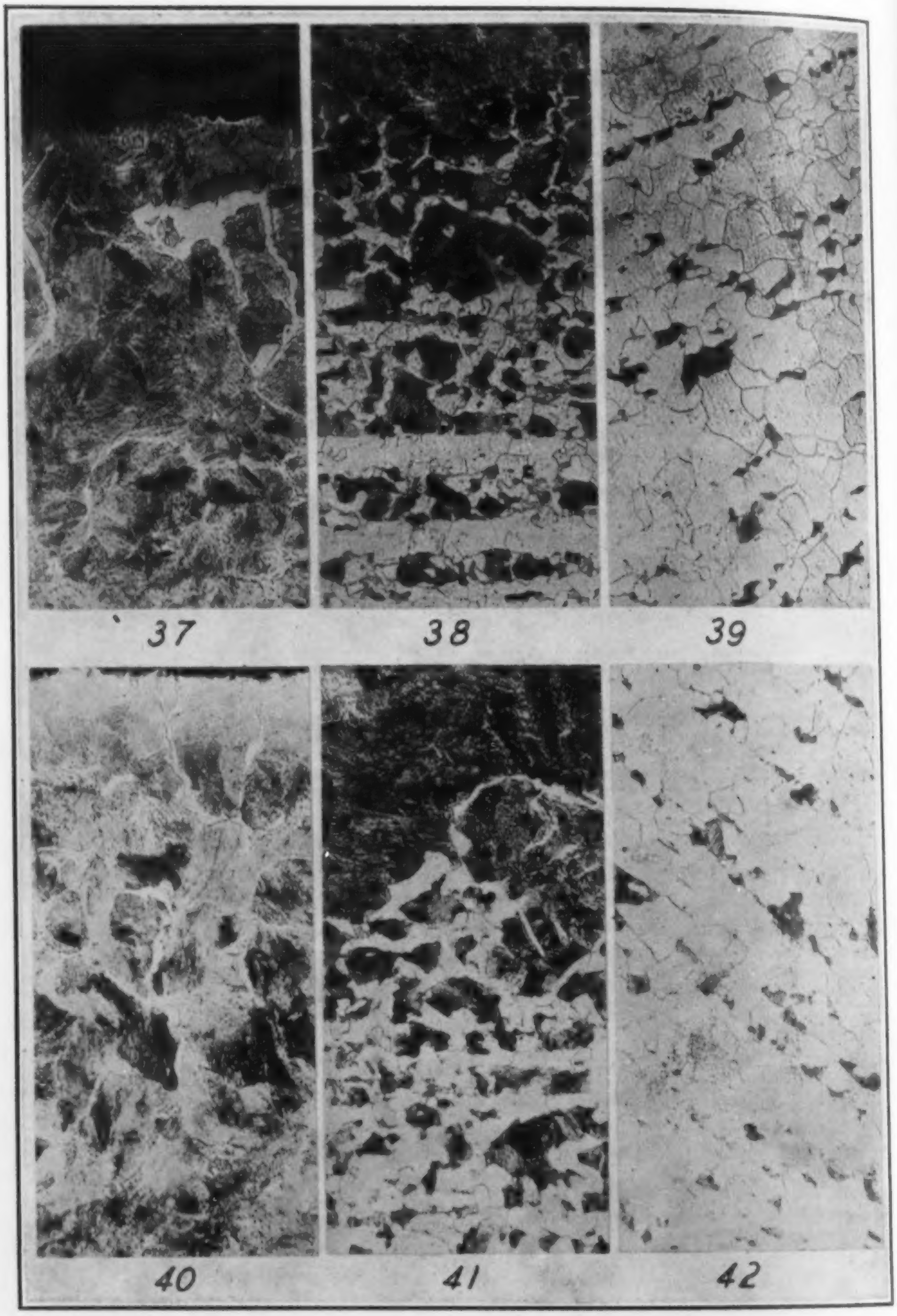
Photomicrographs of Samples from Experiment B. Samples from Tip of Bend. Fig. 19—Hypereutectoid Zone. Fig. 20—Hypoeutectoid Zone. Fig. 21—Core. Photomicrographs of Samples from Experiment B. Samples from Inside of Bend Underneath Tip. Fig. 22—Hypereutectoid Zone. Fig. 23—Hypoeutectoid Zone. Fig 24—Core. All Samples Etched with Nitric Acid. **Magnification 100 x.**



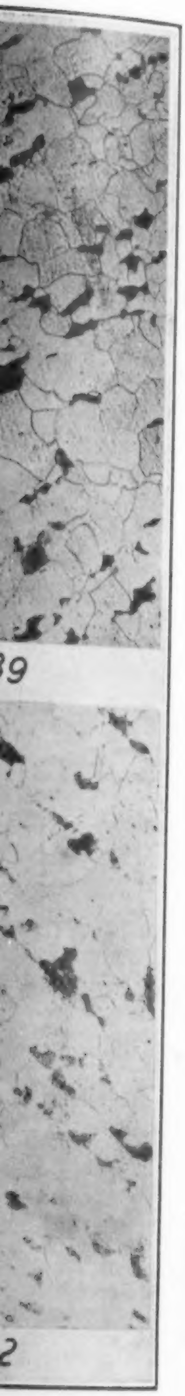
Photomicrographs of Samples from Experiment B. Samples are from the Unstrained Part Outside. Fig. 25—Hypereutectoid Zone. Fig. 26—Hypoeutectoid Zone. Fig. 27—Core. Photomicrographs of Samples from Experiment B. Samples are from the Unstrained Part Inside. Fig. 28—Hypereutectoid Zone. Fig. 29—Hypoeutectoid Zone. Fig. 30—Core. All Samples Etched with Nitric Acid. Magnification 100 x.



Photomicrographs of Samples from Experiment C. Samples from Tip of Bend. Fig. 31—Hypereutectoid Zone. Fig. 32—Hypoeutectoid Zone. Fig. 33—Core. Photomicrographs of Samples from Experiment C. Samples from Inside of Bend Underneath Tip. Fig. 34—Hypereutectoid Zone. Fig. 35—Hypoeutectoid Zone. Fig. 36—Core. All Samples Etched with Nitric Acid. Magnification 100 x.



Photomicrographs of Samples from Experiment C. Samples are from the Unstrained Part Outside. Fig. 37—Hypereutectoid Zone. Fig. 38—Hypoeutectoid Zone. Fig. 39—Core. Photomicrographs of Samples from Experiment C. Samples are from the Unstrained Part Inside. Fig. 40—Hypereutectoid Zone. Fig. 41—Hypoeutectoid Zone. Fig. 42—Core. All Samples Etched with Nitric Acid. Magnification 100 x.



e Unstrained Part
Fig. 39—Core.
Unstrained Part
g. 42—Core. All

inside and outside showed a good hypereutectoid zone which is supersaturated with respect to cementite.

Experiment B. The samples of this experiment at the tip of the bend on the outside show a good hypereutectoid zone which is well saturated with respect to cementite. On the inside of the bend directly underneath the tip the samples show a hypereutectoid zone which is not saturated to the same extent as the hypereutectoid zone, at the tip of the bend. The amount of cementite is much smaller and is present as small fingers instead of surrounding the grains. The unstrained parts of the samples as in the case of experiment A show a hypereutectoid zone which is supersaturated with respect to cementite.

Experiment C. The samples of this experiment show practically the same condition as experiment A with but one exception. The tip of the bend on the outside shows a hypereutectoid zone which is supersaturated with respect to cementite, whereas on the inside of the sample directly underneath the tip there is no hypereutectoid zone.

The unstrained parts of the samples, both inside and outside show the same condition as those of experiments A and B.

Summary. A. Samples stressed and coarse grains produced in these stressed zones by heating at the critical temperature give on carburizing no hypereutectoid zone at outside or inside of the bends.

B. Samples stressed and these stresses relieved by normalizing show a hypereutectoid zone on the inside and outside of bends. But it was noticed in all cases that more carbide was piled up on the outside bend than on the inner bend. This was so in all cases and would show that stresses in tension appear to be more readily removed on normalizing.

C. Samples stressed and carburized but heating up delayed at temperature which would produce coarse grains gave results similar to A, with one exception—the outside of bend showed a small amount of carbide. This delay was 7 hours at critical temperature, whereas in A the samples were held 8 hours at critical temperature.

The above data was in each case taken from two separate checks of 6 and 3 samples each respectively and agreement was complete in all cases.

The further outline of this research is now being done using a vanadium and a non-vanadium type of steels. The preliminary work done agrees with the above done on plain carbon.

E. L. Roff: I would like to ask the question whether there is any marked difference in normal or abnormal structure obtained with the different methods of carburizing? That is, what type of carburizing was used, and what type of mixture or compound?

S. Epstein: We did not make any exhaustive tests as to the different kinds of carburizing. As far as we can tell it makes no difference what kind of carburizing is used.

F. H. Kingdon: As I understand it, in the killed steel, the aluminum was added in the ladle, and then when you come to pour into the mold there was an additional amount of aluminum put into the mold? Also in the one

that had the ferrovanadium, that mold or ingot also carried aluminum, so that you had both aluminum and ferrovanadium?

S. EPSTEIN: Yes. In the killed steels aluminum had already been added in the ladle, 100 pounds of aluminum to a 100-ton heat of steel. That makes about one pound to the ton, and we added about the same amount later in the mold, so that in the killed steel there was a total of two pounds of aluminum per ton. The aluminum addition in the mold caused abnormality in the killed steel, and the same addition caused the same degree of abnormality in the effervescent steel, to which no aluminum had been added previously. The analyses given show the aluminum contents, not in experimental ingots, but in commercial steels which were submitted to us and which we collected over a long period of time. We do not know how the aluminum was added to these steels. Fig. 14 shows simply the total aluminum content and indicates that abnormality was generally associated with a high aluminum content. There were a few exceptions, and it is possible that in the normal specimens which showed a high aluminum content the aluminum was added in the ladle or at some other stage where abnormality is not produced by aluminum.

F. R. PALMER: I would like to ask Mr. Gat a question in connection with his Fig. 24, whether or not he remembers how long a period elapsed between the time that sample was polished and the time it was etched?

J. D. GAT: I do not remember the time. According to my observation I never had any difference in the appearance of cementite after etching it immediately or letting it stand for any amount of time. It seemingly has no effect.

F. R. PALMER: How about the ferrite?

J. D. GAT: You mean the eutectoid? It did not change whatever. It always looked the same. I had that specimen observed about a month after the first observation and even then I did not see any difference.

F. R. PALMER: But it was etched during that month? It was in the etched condition?

J. D. GAT: Yes.

F. R. PALMER: I will tell you why I mention this. It has been my observation that in many cases, soft constituents such as ferrite are so disturbed by polishing, no matter how carefully it is done, that if the samples are etched within a few hours after polishing a peculiar structure results, whereas if the same sample is allowed to stand for 24 or 48 hours before etching, an entirely different structure results. Many peculiar structures will show up shortly after polishing that will not show up 24 or 48 hours later, and I believe that the condition is not generally appreciated, yet it is bound to have a great effect on the published data in connection with photomicrographic studies. I have seen ferrite in large circular structures looking very much like leaves, very striking structures that could be produced immediately after polishing and could not be duplicated 48 hours later on the same sample, and since we are talking here, or the author is talking about a very abstruse phenomena, I believe that that particular feature may enter into the discussion.

J. D. GAT: I could not get any conclusion immediately, so after exami-

nation I etched for cementite with sodium picrate, which took several hours. I etched slightly for cementite, repeated it several times, and etched finally for the substance surrounding it. So between polishing and final etching it was at least six hours.

F. R. PALMER: I think you might still get errors within six hours, not always, but sometimes.

DR. H. W. GILLETT: Mr. Chairman, I would like to ask a question in regard to Mr. Gat's paper, his discussion of that same micrograph on the following page. He says "lack of softness eliminates the possibility of this envelope being ferrite, while the presence of a substance of a carbidic nature is precluded by the composition of the steel. In the footnote is given what I take to be the composition of the steel originally.

J. D. GAT: This analysis refers to the original composition. By "carbidic nature" I mean chromium carbide or some other carbide involving the presence of some other metal besides iron.

DR. H. W. GILLETT: On the other hand, I do not quite see that the argument is complete. Do you not have cementite in the center of that envelope?

J. D. GAT: Yes.

DR. H. W. GILLETT: And did you have cementite with 6-2/3 per cent carbon in the center of that, even though the matrix of the steel is only 0.06 carbon? I cannot see that the proof is absolutely logical that in the material outside of that 6-2/3 per cent you might not have a carbidic nature. I do not believe it is of a carbidic nature, but I do believe that the proof as presented here is not clear enough to justify the statement without giving us some of your other reasons for your conclusions.

J. D. GAT: I could not reach any conclusions before I was able to produce photographs, presented tonight. At the beginning it was only my assumption that it might be a compound of iron and oxygen rather than pure ferrite. When I was able to observe the peculiarities of the structure shown on the slides tonight and found that the amount of the substance rejected to the grain boundaries is not a direct function of oxygen content but varies considerably with the increase of carbon content I had to assume that the latter element has something to do with it, especially when the results of carburization showed almost a direct line relation between the two. We have to assume that the substance at the grain boundaries is of carbidic nature, cementite for example, entirely insoluble in alpha iron, or that we have here a combination of two probable constituents, iron oxides and iron carbides forming a eutectoid alloy. One thing is unmistakable, its ternary composition, but we are at the present in too early stages of investigation even to speculate about the composition of its molecules.

DR. C. H. HERTY: Mr. Chairman, I would like to ask Mr. Gat if he has etched with hydrogen at high temperatures on that particular piece of steel, hydrogen at a 1000 or 1200 degrees Fahr. I think if you etched with hydrogen on that particular envelope you would probably find out what it was.

J. D. GAT: No, I did not try it.

P. E. MCKINNEY: Mr. Chairman, ladies and gentlemen, it seems to me that in going through this discussion, that the papers of both of the authors

have in general been discussing an effect without getting back to a real analysis of the cause. The nearest that I find approaching that is in this sub-paragraph 8d of Messrs. Epstein and Rawdon's paper, in which they refer to obstruction to grain growth. We might better term that obstruction to structural changes.

There is nothing new in what we see here. If any of us have ever stopped to examine the microstructure of one of the old time blister bars, the product of the cementation process where we took Swedish iron full of various kinds of foreign matter and observed the peculiar grain formation of the carburized matter, we could see considerable similarity to the condition discussed here. Not only do we find that condition existing in carburization, but we run into it in such things as steel castings and steel forgings, where we have, you might say, a recalcitrant movement of the grain in a normal heat treatment. I have seen steel castings that had the characteristic dentritic or parallel arrangement of grains which required very drastic high temperature treatments in order to move the grain, in fact, we have had cases where double and triple heat treatments were necessary to get that grain to move. Usually we find that the underlying cause for that is a condition similar to those unetched photomicrographs that were shown first in the presentation of Mr. Gat's paper. They act as barriers to the free migration of the grains and the changing of the structure, not necessarily to the growth of the grains but to any change at all in the structure; and I believe that if more study was given to these abnormal steels by the normal methods for determining quality, such as examinations at high magnifications at times for non-metallic impurities, defects and other characteristics, that you could definitely classify the steels which would act under carburization normally and those which would act under carburization abnormally.

I cannot quite agree that abnormal steels are necessarily just as high quality as the others. They may be suitable for certain purposes, but my own opinion is that a great deal of the normality or abnormality of steel goes right back to the quality of the original steel as melted, and these are underlying inherent properties of the steel itself.

H. S. Rawdon: I think I would prefer to answer most of the points that have been raised by written discussion, rather than try to answer them fully here. I would, however, like to put in a plea for a better name for this phenomenon we have been discussing. This name "abnormal" gets on a person's nerves when you hear it, so that you get your back up and will not believe it, although you are forced to admit that the evidence in favor of "abnormality" can not be controverted. So that if anyone has a better name to suggest in place of "normal" and "abnormal," or "natural," or "unnatural," we would like to have it.

I would also like to refer to some work that we have done along the line that Mr. Palmer spoke of. We have noticed at times in looking at some of these specimens, both in the polished and in the etched condition that something unusual appeared to be in the structure, and we have been quite enthused at times, and felt that we had something along the lines that Mr. Gat has described, that would probably explain the real underlying reason for this difference in these steels. When we come to polish them more or to etch them,

however, we got indications that the structure that we had been looking at had resulted from the polishing, and we had to discard our theory entirely. So we feel that there is an effect, as Mr. Palmer describes, that you can get in the structural appearance of ferrite from the polishing that you give it. It appears that the surface layer must be disturbed in some way so that when you etch it you may get certain markings or patterns in the surface layer as a result of the polishing which may be quite misleading as to the real microstructure of the metal. We have not tried, but we will follow Mr. Palmer's suggestion of letting these specimens rest for 24 or 48 hours between the polishing and etching and see if we still get these peculiar markings.

DR. H. W. GILLETT: It seems to me, Mr. Chairman, that this question of name is really an important one, and we have been searching for a better one. No one objects to the term "normal steel"—that is, everybody agrees that steel that is not abnormal is all right. It is the term "abnormal" that people disagree upon, and it apparently is the connotation of inferiority that comes in there that gives the trouble. I have been wondering whether the terms "ordinary," synonymous with, "normal" and "metallographically extraordinary," synonymous with "abnormal," might not perhaps be a possible substitute. But, at any rate, whatever is selected, I think that there should be very careful thought given to selecting a better name.

W. J. MERTEN: Mr. Chairman, Mr. McKinney, in his remarks about the mobility of metaloids or other detrimental or so-called detrimental abnormal constituents in steel producing that material, indicated that the mobility increases at certain stages of the process of heating of material, and if that mobility can be brought about I can not see any reason why he should have any objection to a piece of material that contains those materials properly located so that there is no longer any detrimental effect visible or detectable by any test that it can be subjected to, except probably carburizing and the production of soft spots by quenching. Is it not after all the physical property of that steel determined by its application in service quality determination, rather than an arbitrary test of quenching it in tap water, which we consider as an unsatisfactory method of producing uniformly hard material?

P. E. MCKINNEY: I can answer that by stating that in general I would rather have an article that had never been broken than to repair something that was broken or wrecked. The steel that has normal characteristics, in so far as retaining its normal physical characteristics by simple heat treatment, differs from one where you have to apply these trick treatments, to the extent that it is free from all of those inherent detrimental influences which may affect its serviceability for a certain purpose. Now, if we can go into the question of simple heat treatments of heavy forgings, we know and have absolutely demonstrated that you can take many forgings which will respond beautifully to heat treatment without any high temperature treatments, without any double and triple quenching and re-treatments; whereas another steel with the same chemical characteristics but with some of these abnormal conditions—what we oftentimes term "dirty steel" can be made to meet those conditions only by unusual treatments, but in studying the value of that steel for service and for structural purposes, it will not stand up as well against

repeated strains and impact tests, and even bend tests, as will these steels that are normal in these respects. Now, that may or not be true in the case of carburizing steel. I should think that the same difficulties would be experienced in the strength and character of those steels for certain purposes, and I believe that regardless of whether by trick heat treatment we can make one of these steels which is recalcitrant to treatment good, that it certainly is not the same and does not possess the same suitability for the purpose intended as has a steel which will respond to the simple and normal treatments without resorting to unusual treatment.

W. J. MERTEN: It is absolutely wrong to consider any normalizing or rectifying or modifying treatments prior to carburization as a trick heat treatment, because after all you have hot-rolled steel, cold-rolled steel, forged steel and drop forged steel, and any other product to go through a carburizing process, and the closer you bring those two steels to the same condition by a prior treatment which may be at a high heat or any other heat, the better your carburizing practice is going to be, because you do know then how to regulate your time, temperature and the proper conditions and practice so as to get uniform results. So trick heat treatments do not apply in the manner and in the same sense as they have been used in the pamphlet.

T. BERGLUND: In abnormal steel, Mr. Gat says there is a much higher percentage of oxygen than in normal steel. I believe that he refers to the average oxygen content of the original steel in the uncarburized state. It would be interesting to obtain oxide determinations on these same steels. I believe that if only the carburized layers are considered in oxygen analyses they will contain a much lower percentage of oxygen than is shown in the average content of untreated steel.

J. D. GAT: Regarding oxygen content and the difference between the results of the Bureau and our figures, I would like to mention that we have to account for non-metallic inclusions, the presence of which strongly handicaps the accurate determination of small amounts of oxygen, because estimation of it by vacuum fusion method will give the same amount of the gas present in an alloy containing all of its oxygen in solution or as a ternary eutectoid or in the form of difficultly reducible oxides, which do not affect the results of carburization at all. For example, in some of the specimens described by Messrs. Rawdon and Epstein, the oxygen content was very high, almost 0.10 per cent. There is hardly any doubt in my mind that after carburization they will show split cementite and will not harden. The results reported showed that the steel did harden and did not have any divorced pearlite. Here we have a nice example of dirty steel having an oxygen content as high as the very abnormal metal. When I was selecting specimens for my experiments I did not pay any attention to non-metallic content and was interested only in the amount of lined cementite. This permitted me to differentiate definitely between high oxygen content and dirty steels. The question regarding the possibility of existence of oxygen in the presence of carbon certainly deserves a considerable amount of study. At the present we have a few data supporting the theory that a steel can contain simultaneously carbon and oxygen. During an investigation of the reactions taking place in the process

of steel making many analyses were made at the different stages of decarburization. In several occasions the percentage of oxygen reached the values observed in over oxidized low carbon steels, though carbon content of the samples in question was in the neighborhood of 0.80 per cent.

One cannot omit here to mention an interesting investigation by Mr. Kurio Yamada, Tohoku Imperial University, Sendai, Japan, published in November, 1926. The experiments were conducted with the purpose of establishing the solubility of carbon in alpha iron. To molten electrolytic iron were added varying amounts of carbon and the structure recorded. The series of photographs presenting the appearance of steels with increasing carbon content showed gradually increasing amounts of the substance at the grain boundaries and close similarity between its appearance and the areas observed in our investigations of high oxygen steels.

Mr. Yamada did not point out the reasons why he was using the term "cementite" in connection with this substance, so much different from well known thin lines or sharp needles, of daily laboratory routine, with the exception of the remark that it was colored by sodium picrate.

Up to 0.06 per cent carbon these boundaries did not change their appearance and were increasing only in number. After passing this point the first traces of pearlite began to appear in continually larger volume. The correct understanding of the phenomena taking place is handicapped by unfortunate omission from analysis of steel used or any data relative to the gas content, especially oxygen.

With due apologies to Mr. Yamada for the liberty taken in interpretation of his results, I am tempted to think that the iron used as the base for preparation of alloys in question probably contained some oxygen, not a large amount as sometimes observed in commercial steels, but still perceptible. The small amounts of carbon present in the first specimens of the series were, seemingly, entirely absorbed in iron-carbon-oxygen eutectoid alloy, until all oxygen present was transformed in it, which occurred at 0.06 per cent carbon. After this the carbon was left free to combine directly with the iron, resulting in pearlite. Before making any definite conclusions we must, however, conduct a very considerable amount of experimental work and to approach the subject not only from purely chemical point of view but to try to construct an equilibrium diagram of iron-carbon-oxygen system with the help of properly selected etching reagents and high power micrography.

F. R. PALMER: May I ask a question, please? What etching did you use to bring out this new constituent?

J. D. GAT: On low carbon steels, in the core of carburized specimens, I was using relief polish followed by Le Chatelier reagent so as to bring out the outlines more sharply, after which a light touch on finest alumina wheel gave all that could be expected. I am inclined to think that etching with sodium picrate somewhat more intense than that necessary for cementite gives quite satisfactory results with less trouble than relief polish. Only in case when one wishes to bring out the film around pearlitic grains, relief polish is obligatory, preferably followed by a very light etch with picric or nitric acid to develop the constituents of the enclosed pearlite.

S. EPSTEIN: I want to reply to some of the points that have been brought up. I want to comment on those of Mr. Merten first. He has read his discussion showing that if you cold work or strain steel it will have an abnormal structure, whereas if you normalize steel it will have a normal structure. Is that the point?

W. J. MERTEN: No.

S. EPSTEIN: That is, you get a difference in structure depending on the degree of straining of the steel?

W. J. MERTEN: Exactly.

S. EPSTEIN: I want to make it clear that this does not in any way refute the existence of abnormal steel. It may be very true that sometimes if you strain steel in a certain way, it will give a different carburized structure. However, the samples used in our investigation were not strained. They were taken from the ingot or rolled bar, then carburized, and the different structures were obtained. There was no question of any straining. In experiments in which we strained, cold-worked, and heated bars in various ways, the normality or abnormality of the structures did not seem to be affected. There our results disagree with yours, and it might be worth while for us to repeat those experiments. But even if it should prove that straining does affect the normality or abnormality of the steel in some way, it would not follow that abnormality does not exist, or that it is simply due to straining. As I have said, the normal and abnormal structures were studied in specimens in which there was no question of straining.

How do you explain the fact that, as shown in Table I, when normal and abnormal steel were treated in exactly the same way, practically every time there was a decided difference in the number of soft spots between the normal and abnormal samples?

As regards surface discoloration it should be explained, as was stated in the paper, that there was no difference between the normal and abnormal specimens. The extent of the discolored areas was exactly alike, as may be seen by comparing the paired specimens in Figs. 5, 6, 7, and 8. The point is that in the abnormal samples most of the discolored areas were soft, troostite having appeared in those spots because of the retarded cooling. In the normal samples, on the other hand, in similar discolored areas with the same retarded rate of cooling, there were less soft spots, martensite usually having appeared, because of the slower critical cooling rate necessary for the formation of martensite in normal steel. A normal steel hardens a bit more readily so that generally no soft spots are produced, even if the surface is discolored by the presence of a gas bubble.

W. J. MERTEN: It is not a matter of surface condition which is visible to the eye; it is a microscopical condition which is a roughening of the surface during the cooling, whereby a clinging effect is produced for the vapor formed, and that vapor clings on the surface, which has a fine granular cementite, rather than on the large polygonal grains with a network of cementite around it.

S. EPSTEIN: You are simply going to a further explanation.

W. J. MERTEN: No, the explanation is proven by the quenching test.

I can prove that point by quenching materials without the vapor, and I get results that are uniform.

S. EPSTEIN: Granting your contention, suppose I said that a normal steel had a certain surface and an abnormal steel had a different surface—therefore, the two steels are different. Isn't that logical?

W. J. MERTEN: Yes, but you are trying to prove an abnormality or structural abnormality by a soft spot.

S. EPSTEIN: This is what I am saying—a normal steel will quench with less soft spots.

W. J. MERTEN: No, it does it only in tap water. Tap water is no quenching medium. That is an admission good to prove the contention.

S. EPSTEIN: But quenching in tap water shows up a difference between the two. A normal steel when quenched in tap water will show less soft spots than an abnormal steel.

W. J. MERTEN: But not because you have structural irregularities, but because you have a surface condition which produces a vapor clinging effect which does not extract heat sufficiently strong to dispel it.

S. EPSTEIN: Well, let us suppose the difference is in the kind of surface. Wouldn't that indicate that it is a different kind of steel? There is something in there to cause that surface to be different.

W. J. MERTEN: You show by the structure, by the photomicrographic picture that it is a different structure.

S. EPSTEIN: It is a different steel then. I am not saying it is bad or good. I am simply saying there is such a thing as normal and abnormal. There is the structural difference; and whether it is because of the surface effect, or what not—let us not try to explain it for the moment—a normal steel will give less soft spots when quenched in tap water, and an abnormal steel will give more soft spots when quenched in tap water. Isn't that a fact?

W. J. MERTEN: No, Mr. Epstein. You say in your paper that you quench drastically in one case and in the other case you quench mildly. That is not the case. You are missing the issue entirely. In one case you are quenching with a cold vapor effect uniformly, and in the other case you quench just as hard but irregularly. That is the condition.

S. EPSTEIN: But I quench both types together in pairs. I treat them exactly alike and it is not as though the abnormal sample had more soft spots, and the normal sample less only once, but it comes out the same way time after time. As may be seen in Table I, after every quenching in a medium in which soft spots were obtained, in about 60 pairs of specimens, the abnormal samples had more soft spots.

Authors' Reply to Discussion by Epstein and Rawdon

To reply in detail to all the points brought up in discussion would require a rather lengthy treatment, which the authors have decided not to go into at this time. Work has been continued on the problem at the Bureau of Standards, and a complete report will be issued as a Bureau publication. A summary may be given of some of the results which have

been obtained since the paper was presented, and which bear on the discussion. In a systematic series of tests normal steel gave on the average, a 10 per cent deeper case than abnormal steel. Effervescent steels gave very few more soft spots than killed steel and the difference between killed and effervescent steel in this respect, was negligible compared to the decided difference between normal and abnormal steel. The existence of the "iron-carbon-oxygen eutectoid" described by Mr. Gat has so far not been confirmed and evidence has indicated that its appearance is very probably due to some polishing and etching effect. Further oxygen analyses have given comparable results to those previously reported, in which total oxygen content seemed to bear no obvious relation to abnormality. In regard to Mr. Merten's discussion that the strains at the bend of specimens bent into a U shape, affected the depth of carburization, tests indicated that the shallower carburized layer at the bend inside the U was due to a lower concentration of carburizing material at that point, that is, it was due to the shape of the specimen, rather than to the compressive strains. In regard to Mr. McKinney's discussion that an abnormal structure is probably an indication of some underlying defect or weakness in mechanical properties, the results of impact tests of normal and abnormal steel are of interest. After a carburizing treatment, the core of abnormal steel showed considerably higher impact resistance than normal steel as might be expected from the finer grain of abnormal steel. When the carburizing treatment was followed by the "regenerative heat treatment", however, the impact resistance of the normal and abnormal steel was the same. All of the above work has tended to confirm the conclusions given in the paper and not to modify them materially. Those interested in the full details are referred to the forthcoming Bureau publication.

Authors' Reply to Discussion by J. D. Gat

It seems to me, Mr. Chairman and gentlemen, that the point of maximum importance in my paper, the existence of iron-carbon-oxygen eutectoid in unhardenable oxygenated steels, was not illuminated with experimental evidence and observations with fullness warranted by the importance of the subject.

While all the members of this meeting who had an opportunity to approach critically the behavior of steels having different grain size will probably agree with at least some of the opinions expressed and conclusions reached in the first part of the paper related to the treatment of this phase of the subject and supported by a considerable amount of experimental data omitted from the paper, anyone is entirely justified to take with reserve my assertions regarding the existence of this important eutectoid unless some more proofs are produced.

Hardness and microscopical appearance of the substance surrounding cementitic mesh can serve only as indices of its being of different nature than ferrite. Theoretical considerations deduced from the properties of the iron-carbon system as expressed in the equilibrium diagram, throw some light on it, but any statement of this type must necessarily be of a tentative character.

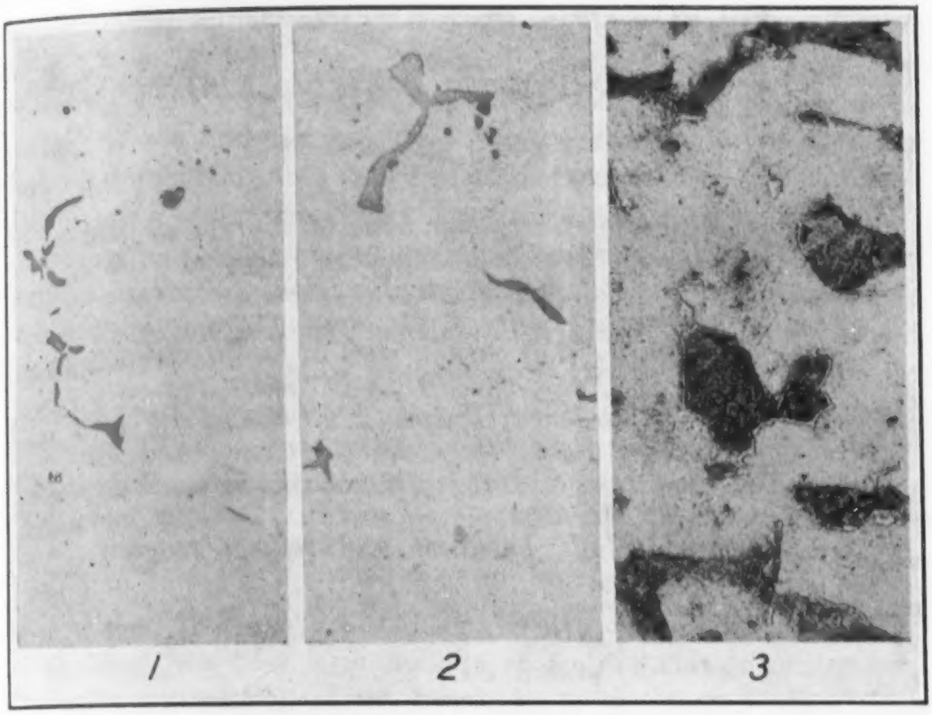


Fig. 1—Core of a Carburized Specimen. Carbon 0.02 Per Cent, Oxygen 0.10 Per Cent. Etched with Sodium Pictrate. 500 x.

Fig. 2—Core of a Carburized Specimen. Carbon 0.06 Per Cent, Oxygen 0.10 Per Cent. Etched with Sodium Picrate. 500 x.

Fig. 3—Gradation Zone of the Same Specimen as Fig. 1. Carbon About 0.20 Per Cent, Oxygen 0.10 Per Cent. Polished in Relief and Slightly Etched with Nitric Acid. 100 x. Note Boundaries of Eutectoid Alloy.

Examining the core of carburized high oxygen steels it is not difficult to see that a substance dissimilar to the mass of ferrite is rejected to the grain boundaries. Its appearance does not suggest any of the already known constituents of steel. It seems to be harder than the ferritic matrix and can be brought out comparatively easily by relief polishing. As one never encounters it in completely deoxidized steels it is natural to expect here an iron-oxygen compound, though the color of it does not resemble any of the known oxides. Should it be an oxide of iron insoluble in ferrite at room temperature one can expect that a definite oxygen content would specify a given amount of it rejected at the grain boundaries. In three steels selected to illustrate this point the oxygen content was the same, 0.10 per cent, but the percentage of carbon varied. Looking at a very low, 0.02 per cent carbon steel one can see only a few inclusions of this type. With 0.06 per cent carbon their number increases and when the carbon was raised by carburization to about 0.20 per cent every grain of pearlite was surrounded by a film of this substance. Its percentage increases with increasing carbon content until in the hypereutectoid zone it strongly predominates over pearlite and cementite. (Figs. 1, 2 and 3 above.)

(Continued on Page 478)

EFFECT OF TEMPERATURE ON THE MECHANICAL AND MICROSCOPIC PROPERTIES OF STEEL

By George C. Priester and Oscar E. Harder

Abstract

The authors of this paper have in a previous paper described the mechanical and microscopic properties of a 0.16 per cent carbon steel at various temperatures. This paper describes the results obtained on tests of a quenched 0.29 per cent carbon steel at temperatures up to 1112 degrees Fahr. (600 degrees Cent.) and on the same steel as hardened, tempered at temperatures up to 1112 degrees Fahr. (600 degrees Cent.) and then tested at room temperature. Only tensile strength tests were made at elevated temperatures. Tests at room temperature include hardness and impact toughness.

THE authors have previously published a paper of their investigation of this subject as applied to a 0.16 per cent carbon steel.[1] Since that report appeared, R. O. Griffis[2] has discussed our paper and has raised a question regarding the editorial summary, "Properties of a low-carbon steel in the blue brittle range are inherent to that temperature and are not duplicated when same metal is tested at room temperature after a corresponding tempering." Mr. Griffis calls special attention to the extensive investigation by Dr. Fettweis.[3]

In Dr. Fettweis' paper it has been shown that blue brittleness, or at least a similar property of metals, can be produced in a number of different ways, one of which is by heating to a somewhat elevated temperature and testing the material in tension.

It was not the intention of the writers in the previous article to make a claim that this was the only method by which this property of metals could be produced. The distinction was made between the properties of the steel when tested at elevated

[1] *Chemical and Metallurgical Engineering,* Vol. 28, No. 3, January 17, 1923, pp. 3-7.

[2] *Chemical and Metallurgical Engineering,* Vol. 28, No. 5, January 31, 1923, p. 196.

[3] Dr. Fettweis, *Stahl und Eisen,* 1919, pp. 1-7; 34-41.

Of the authors, George C. Priester is Associate Professor of Mathematics and Mechanics, and Oscar E. Harder is Professor of Metallography, University of Minnesota.

temperature and the same steel when heated to this temperature, as in tempering, and then tested at ordinary temperature. It, of course, introduces another field of investigation when stress is applied at the elevated temperature, the specimen cooled to ordinary temperature and then tested in tension. It was expected and clearly understood that the strength of the hardened steel when tested at ordinary temperature would be decidedly higher than what other investigators had found when they worked with annealed specimens or specimens which had had a high temper. However, it was felt that this was the most reasonable way of making the tests in order to determine the particular thing under investigation. The results which are reported in this paper are from a series of similar tests and in general tend to confirm our original conclusions.

Scope of Present Investigation

The research reported includes tests on a quenched 0.29 per cent carbon steel at temperatures up to 1112 degrees Fahr. (600 degrees Cent.), and on the same steel as hardened, tempered at temperatures up to 1112 degrees Fahr. (600 degrees Cent.) and then tested at room temperature. Only tensile strength tests have been made at elevated temperatures, while the tests at room temperature have in addition included hardness and impact toughness. The microstructures are of the specimens tested at elevated temperatures.

The steel used has the following chemical analysis:

Carbon	0.29	Manganese	0.62
Phosphorus	0.10	Silicon	0.045
Sulphur	0.38		

The apparatus, a sketch of which is shown in Fig. 1, and the method of testing have been the same as those reported in the previous paper.

Heat Treatment

All samples were annealed ½ hour at 1652 degrees Fahr. (900 degrees Cent.) and air cooled. Reheated to 1607 degrees Fahr. (875 degrees Cent.), held at that temperature for ½ hour, then quenched in water at 59 degrees Fahr. (15 degrees Cent.).

Those tested at high temperatures were heated to the desired temperature, held for ½ hour, and then tested. Those which were tested in the tempered condition were held ½ hour at the tempering temperature, then tested at room temperature.

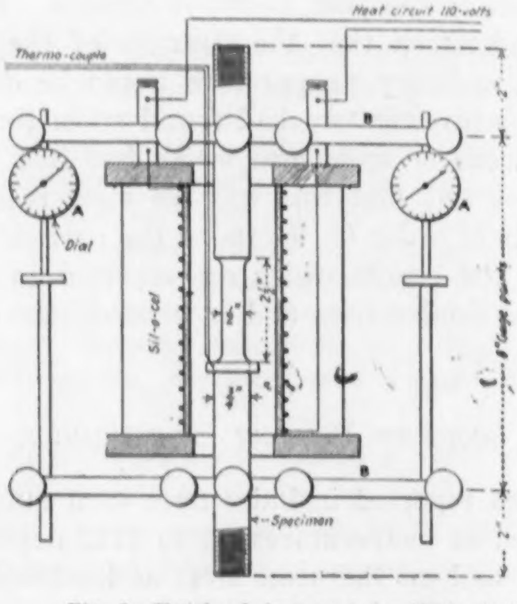


Fig. 1—Sketch of Apparatus for Mechanical Tests at Elevated Temperature.

Effect of Temperature of Testing on the Character of Fracture

The character of the fracture of these quenched 0.29 per cent carbon steel specimens when tested at different temperatures is shown in Fig. 2.

These specimens are arranged with increasing temperature, from room temperature to 1112 degrees Fahr. (600 degrees Cent.) from left to right. These fractures are about what might be expected from the results of the tests and from the microstructures. Those specimens tested at not over 392 degrees Fahr. (200 degrees Cent.) were still in the hardened condition. At 572 degrees Fahr. (300 degrees Cent.) there is a marked increase in the elongation and reduction of area (note the necking at the point of rupture) while the tensile strength, proportional limit, and impact toughness are practically unchanged. There is also a change in the microstructure.

Mechanical Properties of Quenched 0.29 Per Cent Carbon Steel at High Temperatures

The results of the tests at various temperatures are given in Table I and are shown graphically in Fig. 4. For convenience

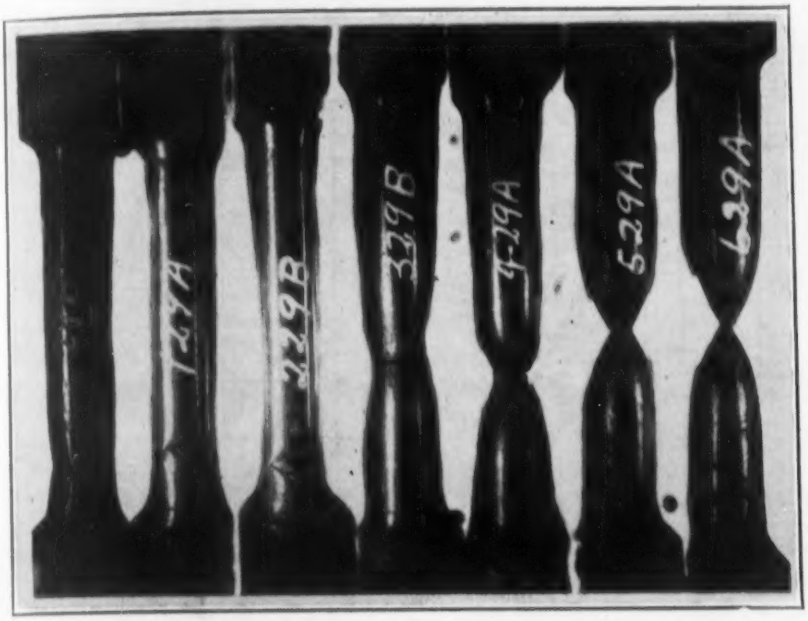


Fig. 2—Character of Failures of Tensile Test Bars of Hardened 0.29 Per Cent Carbon Steel When Tested at Temperatures from About 68 to 1112 Degrees Fahr. (20 to 600 Degrees Cent.).

in making comparisons the graphs obtained for the 0.16 per cent carbon steel are reproduced in Fig. 3.

Table I

Mechanical Properties of Quenched 0.29 Per Cent Carbon Steel at High Temperatures

Specimen Number	Temperature of Test, ° F.	Maximum Strength, Lbs./Sq. In.	Proportional Limit, Lbs./Sq. In.	Reduction in Area, %	Elong., %
29A	68	149,000	88,800	8.6	5.0
29C	68	148,500	91,300	2.7	4.0
129B	212	140,100	66,400	5.6	2.0
129C	212	138,500	68,700	5.1	2.0
229A	392	144,800	75,800	...	...
229B	392	143,000	76,100	11.6	4.0
329A	572	148,500	73,300	31.6	11.5
329B	572	150,500	71,300	51.7	21.0
329O	662	117,000	63,600	63.8	21.0
329N	662	125,000	61,000	58.8	17.0
429A	752	95,800	48,700	77.3	23.0
429B	752	89,000	50,800	81.3	23.0
529A	932	50,300	27,900	90.8	26.0
529B	932	48,300	27,900	92.2	28.0
629A	1112	19,300	7,700	95.8	35.5

We find a falling off in the ultimate strength and proportional limit of the steels in the region of about 212 degrees Fahr. (100 degrees Cent.), and a maximum in these properties at about 572 degrees Fahr. (300 degrees Cent.) for the ultimate strength and at 482-572 degrees Fahr. (250-300 degrees Cent.) for the

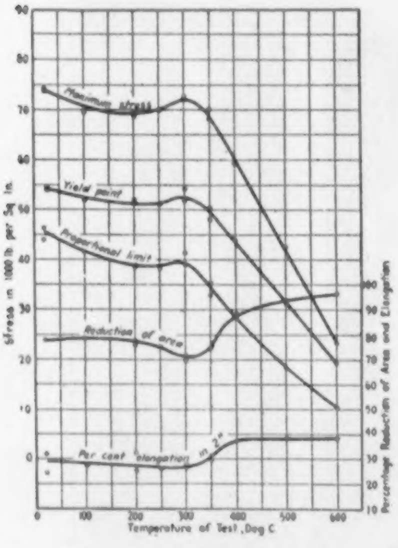


Fig. 3—Mechanical Properties of Quenched 0.16 Per Cent Carbon Steel at High Temperatures.

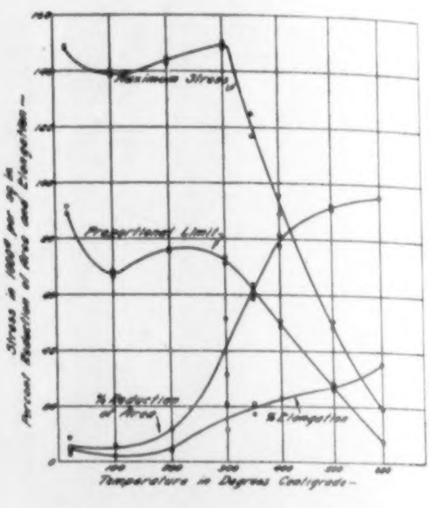


Fig. 4—Mechanical Properties of Quenched 0.29 Per Cent Carbon Steel at High Temperatures.

proportional limit. There are no well marked maxima or minima in the reduction of area and elongation curves. There is, however, a much more pronounced increase in reduction of area and elongation for the specimens tested at 572 degrees Fahr. (300 degrees Cent.). This is probably due to a tempering of the steel at that temperature.

Mechanical Properties of Quenched and Tempered 0.29 Per Cent Carbon Steel

Table II shows the properties of this steel when quenched and tempered at different temperatures but tested at room temperature.

These results are also shown graphically for the 0.16 per cent carbon steel in Fig. 5 and those for the 0.29 per cent carbon steel in Fig. 6.

It will be noted that the ultimate strength of the quenched

Table II

Effect of Tempering Temperature on the Properties of Quenched 0.29 Per Cent Carbon Steel

Specimen Number	Tempering Temperature of Test, ° F.	Maximum Strength, Lbs./Sq. In.	Proportional Limit, Lbs./Sq. In.	Reduction in Area, %	Elong., %
29A	No Temper	172,400	96,400	2.4	1.5
29B	No Temper	180,100	91,400	2.6	1.0
129B	212	177,500	93,800	1.2	1.0
129C	212	175,000	91,200	1.2	1.0
229B	392	168,100	91,400	6.2	3.5
229C	392	170,800	89,200	6.0	2.0
329B	572	176,200	88,200	7.4	3.5
329C	572	165,300	86,300	7.5	3.0
429A	752	150,100	89,200	23.2	8.0
429B	752	127,200	78,900	38.8	10.5
529A	932	112,200	71,600	57.4	15.5
529B	932	116,500	76,600	51.9	15.5
629A	1112	94,700	68,500	66.5	22.0
629B	1112	93,200	61,100	65.1	22.0
NA 29	Annealed	69,900	33,800	59.7	35.0
NB 29	Annealed	69,600	35,900	61.6	34.0

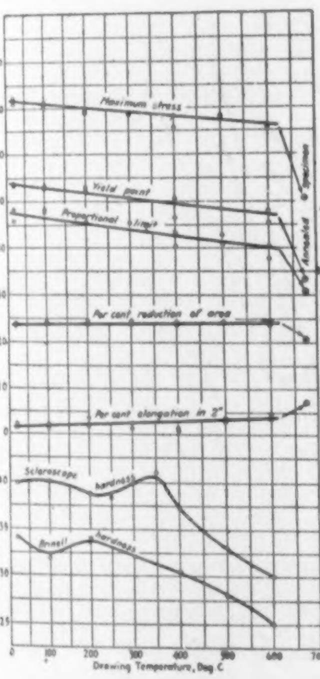


Fig. 5—Properties of Quenched and Tempered 0.16 Per Cent Carbon Steel.

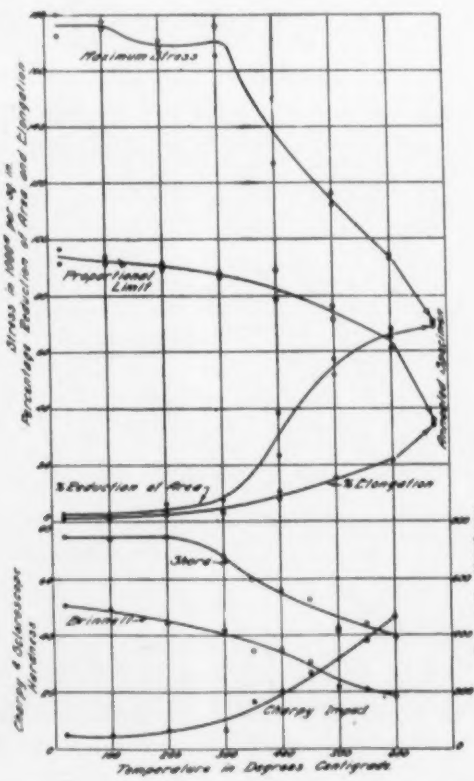


Fig. 6—Properties of Quenched and Tempered 0.29 Per Cent Carbon Steel.

and tempered specimens is considerably higher than the corresponding strengths of the specimens tested at elevated tempera-

ture. This is attributed to the more effective hardening of the smaller specimen used in these tests, the specimens having been turned down to the standard 0.505-inch test specimen and quenched in that condition, while the specimens tested at elevated temperatures had a 12-inch over-all length and therefore greater mass. We do not find the same regularity in the slope of the maximum stress with this steel that we did with the lower carbon steel. This is probably due to the fact that with higher carbon there is a considerable amount of martensitic structure produced and this structure does not entirely disappear until a temperature of more than 392 degrees Fahr. (200 degrees Cent.) is used in the tempering or testing operation. See photomicrograph 229B, Fig. 9.

Effect of Tempering Temperature on Hardness and Impact Toughness of 0.29 Per Cent Carbon Steel

The results of the hardness and impact tests on the quenched and tempered samples are given in Table III, and are shown graphically in Fig. 6. Probably the most significant result is the marked increase in the Charpy impact value after the 662-degree Fahr. (350 degrees Cent.) temper as compared with the 572-degree Fahr. (300 dgrees Cent.) temper.

Microscopic Examination

The photomicrographs shown are of the specimens which were tested at elevated temperatures. Because the temperature was held constant for 30 minutes before testing it is expected that the same structure will be found in the two series of tests, as the tempering was also for 30 minutes at the different temperatures.

Microstructures. The microstructures of these steels show that in the hardened condition they were largely martensite with some troostite, and it was observed in examining the specimens that at the surface the martensite predominated and in the interior the troostite was more prominent. This was to be expected because simple carbon steels are not deep hardening. It will be observed from the photomicrographs that much of the martensite remains after testing at 392 degrees Fahr. (200 degrees Cent.), but that it has disappeared when the specimens

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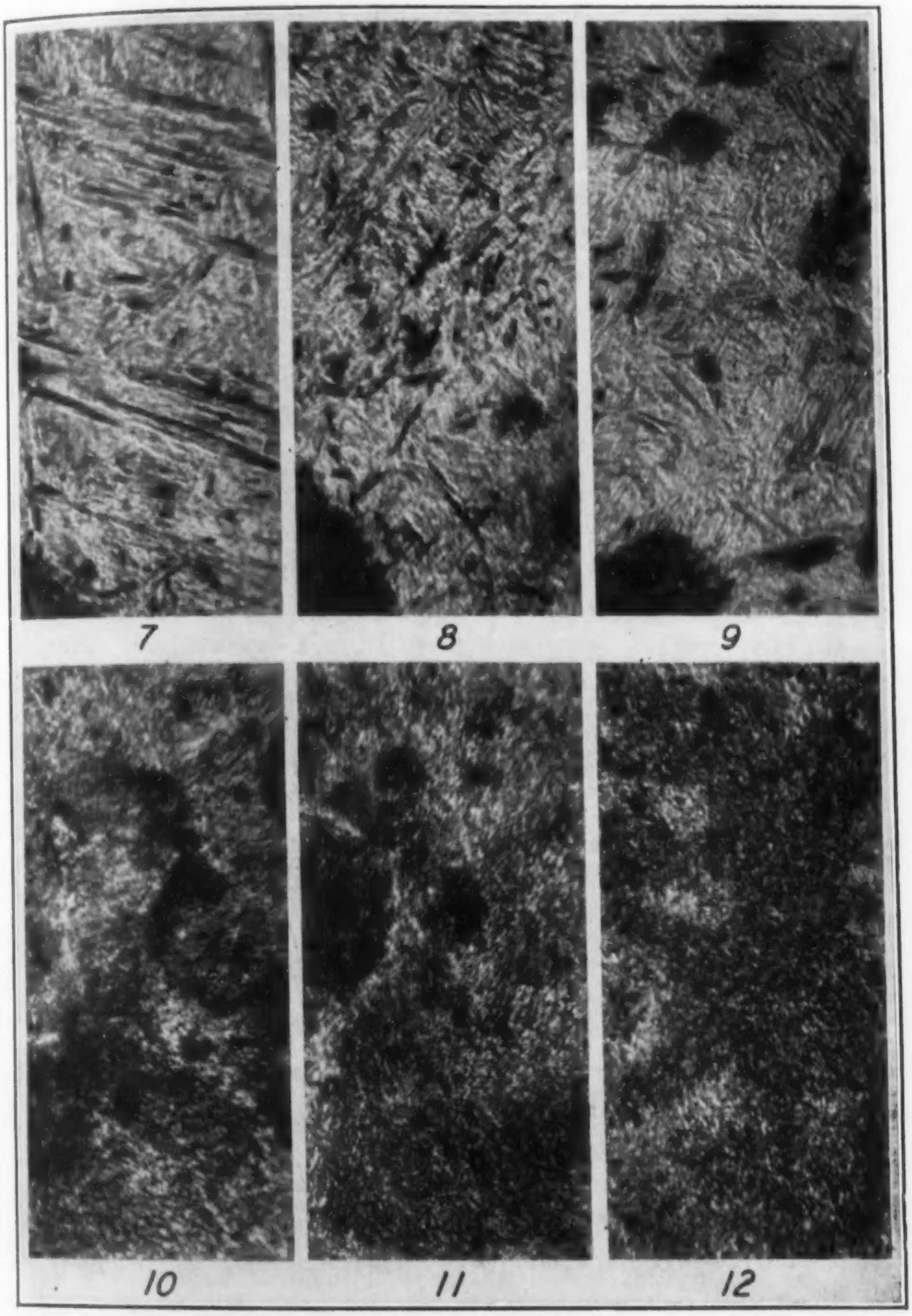

Fig. 7—Photomicrograph of Steel 29A Hardened and Then Tested at Room Temperature.
Fig. 8—Photomicrograph of Steel 129B Hardened and Then Tested at 212 Degrees Fahr.
Fig. 9—Photomicrograph of Steel 229B Hardened and Then Tested at 392 Degrees Fahr.
Fig. 10—Photomicrograph of Steel 329A Hardened and Then Tested at 572 Degrees Fahr.
Fig. 11—Photomicrograph of Steel 429A Hardened and Then Tested at 752 Degrees Fahr.
Fig. 12—Photomicrograph of Steel 629A Hardened and Then Tested at 1112 Degrees Fahr.
All Photomicrographs Were Made at a Magnification of 1000 x.

Table III
Effect of Tempering Temperature on Hardness and Impact Toughness of 0.29 Per Cent Carbon Steel

Specimen Number	Tempering Temperature Degrees Cent.	Shore Hardnees Number	Brinell Hardness Number	Charpy Impact Foot-pounds
A	None	75	512	5.0
B	None	74	495	5.0
A	100	70	487	4.0
B	100	77	495	5.0
A	200	74	430	7.0
B	200	75	452	6.5
A	300	67	418	6.0
B	300	69	416	7.0
A	350	60	340	17.0
B	350	60	340	16.5
A	400	55	341	20.0
B	400	57	351	20.5
A	450	52	302	28.0
B	450	53	302	25.0
A	500	44	232	39.0
B	500	41	198	44.5
A	550	44	202	38.0
B	550	44	215	38.0
A	600	40	187	45.5
B	600	38	179	47.0

Note: Specimens were quenched in water and then tempered ½ hour at the temperatures shown in the table.

were tested or tempered at 572 degrees Fahr. (300 degrees Cent.). the structure being entirely troostitic. For the specimens tested at higher temperatures there appears to be the gradual transition to the sorbite, and finally a coarsening of the sorbitic structure.

Summary of Results and Conclusions

When a 0.29 per cent carbon steel was quenched and then tested in tension at various temperatures up to 1112 degrees Fahr. (600 degrees Cent.) the following results were found:

(1) The maximum stress showed a falling off in the range 212 to 392 degrees Fahr. (100 to 200 degrees Cent.) but a maximum at 572 degrees Fahr. (300 degrees Cent.) above which it fell off rapidly.

(2) The proportional limit showed a marked minimum at 212 degrees Fahr. (100 degrees Cent.) and a maximum is indicated between 392 and 572 degrees Fahr. (200 and 300 degrees Cent.).

(3) The reduction of area showed a marked increase at 572 degrees Fahr. (300 degrees Cent.) as compared with 392 degrees Fahr. (200 degrees Cent.), which change seems to be closely related to the change in the microstructure. There is also a rapid increase in the reduction of area from 572 to 752 degrees Fahr. (300 to 400 degrees Cent.), which is probably related to the further breaking down of the hardened structure. It should be pointed out that in the case of the quenched and tempered specimens the region of rapid increase in the reduction of area is from 572 to 932 degrees Fahr. (300 to 500 degrees Cent.) as compared with 392 to 752 degrees Fahr. (200 to 400 degrees Cent.) for those tested at elevated temperatures. Above this temperature the curve tends to flatten out.

(4) The changes in the elongation curve are less pronounced.

(5) The ratio of proportional limit to tensile strength remained fairly constant at about one-half for the specimens tested at elevated temperatures while for the tempered specimens tested at room temperature the ratio is somewhat higher, particularly for the high tempers where it is about two-thirds.

(6) In the case of the quenched and tempered specimens the Shore hardness curve seems to resemble the ultimate strength curve while the Brinell hardness curve is more like the proportional limit curve.

(7) The impact values for the quenched and tempered specimens show a marked increase at 662 degrees Fahr. (350 degrees Cent.) which is in fair agreement with the increase in the reduction of area.

(8) Our results indicate that in reporting data for tests on iron and steel at elevated temperatures the exact composition, details of heat treatment, and method of testing must be carefully considered and reported. A pronounced change is indicated as the carbon content increases.

(9) The microstructures show little or no breaking down of the hard structures at or below 392 degrees Fahr. (200 degrees Cent.). There is a decided breaking down at 572 degrees Fahr. (300 degrees Cent.) and this is followed by a pronounced increase of the size of the carbide particles in the range 752 to 1112 degrees Fahr. (400 to 600 degrees Cent.).

PROPERTIES AND HEAT TREATMENT OF CAST IRON FOR DIESEL ENGINES

By Francis B. Coyle

Abstract

The author points out that with the increasing use of the Diesel engine there is a growing demand for a higher quality cast iron to withstand the higher working temperatures and higher pressures in Diesel engine operation.

Cast iron is now being produced with a tensile strength which is markedly increased over that of the cast irons produced only a few years ago.

Considerable research remains to be done in the field of heat treatment of cast iron but the author believes that research should be directed toward compositions which have a lower carbon and silicon content than have usually been produced in the past.

Introduction

WITHIN recent years, one of the outstanding developments in industry (at least in the field of prime movers) is the Diesel engine. The demand for a prime mover requiring minimum attendance, space and weight, as well as reduced fuel costs; the demand for a more efficient power plant for transportation on land; the need of power generators of lighter weight and volume for marine transportation (both surface and submarine) are the chief reasons why this development has occurred.

The occurrence of higher pressures and temperatures in Diesel engine operation than is encountered with other types of internal combustion power generators has created a demand for materials of greater strength at normal and elevated temperatures, as well as of much better quality. Of engineering materials, the cheapest and the one possessing the greatest flexibility in the manufacturing process, is cast iron. This material can be easily cast into intricate forms and can be easily machined. It

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A paper presented before the Boston Chapter of the Society, December, 1926. The author, F. B. Coyle, is a member of the research staff of the International Nickel Co., New York City.

is also possible now to produce cast iron possessing comparatively high tensile strength.

There are at least two processes by which cast iron can now be produced with a tensile strength in excess of 50,000 pounds per square inch. The grade of cast iron manufactured in most plants prior to the World War would average between 20,00 and 30,000 pounds per square inch tensile strength. A few plants were able to produce cast iron with a tensile strength greater than 30,000 pounds per square inch, but these were few. At the present time a large number of foundries are producing cast iron with a tensile strength ranging from 30,000 to 35,000 pounds per square inch and a few which can exceed the latter figure. Tensile strength is used by the writer in preference to transverse breaking load because the stresses developed in Diesel engines from thermal and mechanical sources are essentially tensile in nature. Since no reliable relation between tensile strength and transverse breaking load exists, tensile strength is used as a criterion.

Characteristics of Cast Iron

Cast iron is essentially a mechanical mixture of steel and graphite. Hence it is to be expected that the resulting material will possess some of the characteristics of both materials. The extent to which the properties of any one of the constituents will predominate will depend upon the nature of the mixture. The steely matrix can correspond to steel with a carbon content varying from 0.10 to more than 2.50 per cent depending upon the composition and the rate of cooling. For the same reasons, the graphite may vary from 0 to more than 2.50 per cent. The graphite may occur as fine, well distributed particles, or as intermediary forms and sizes to coarse flakes. When the combined carbon of the steel-like matrix is less than that corresponding to a eutectoid steel (that is, to 0.90 per cent carbon) it is called ferritic. When it corresponds to the eutectoid ratio it is called pearlitic. When it is greater than the eutectoid it is either mottled or white.

Fig. 1 shows a constitutional diagram for cast iron presented by Maurer.[1] The various areas represent the structure of cast iron of compositions within that area when cooled under ordinary

[1] Maurer, *Kruppsche Monatshefte*, July, 1924.

sand casting conditions. However, by either accelerating or reducing the rate of cooling the structure of an iron corresponding to one area may be made to correspond to the structure of another area, although the chemical composition is unaltered. In area I of this diagram the structure is white or chilled, that is, the carbon is all combined and the constituents will be either

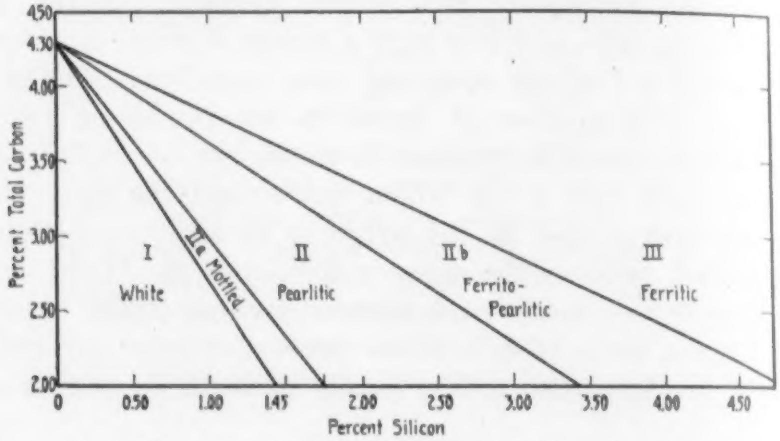


Fig. 1—Constitutional Diagram of Cast Iron—Maurer.

solid solution, eutectic, or both. In area II a, the fracture will be mottled or the components will be iron carbide, pearlite, and graphite. In area II, the components will be a pearlite matrix and graphite. In area II b, the matrix will consist of ferrite and pearlite, pearlite predominating, and the remaining component will be graphite. In area III, the matrix will be pearlite and ferrite, ferrite predominating, and the matrix will be broken up by graphite.

In Fig. 2, the results of more than three thousand tensile tests, which have been conducted during the past ten years, have been superimposed on Fig. 1. Each point was plotted according to chemical composition, but was given a designating mark denoting a range of tensile strength. The ranges included a variation of 5000 pounds per square inch. After the various points had been plotted it was possible to mark off areas corresponding to ranges of tensile strength. In Fig. 2, all compositions within the area NPTS will possess a tensile strength greater than 40,000 pounds per square inch if cooled at a normal rate (ordinary sand casting cooling rate). It will be noted that this area falls within the pearlitic zone of Fig. 1. However, it is also to be

noted that a pearlitic matrix does not necessarily correspond with maximum tensile strength. But compositions within the areas shown will give the indicated tensile strength when cooled at normal rates. The normal rate of cooling for compositions included in area NPTS is about 1000 degrees Fahr. (538 degrees Cent.) per minute. That is the rate of cooling between the pour-

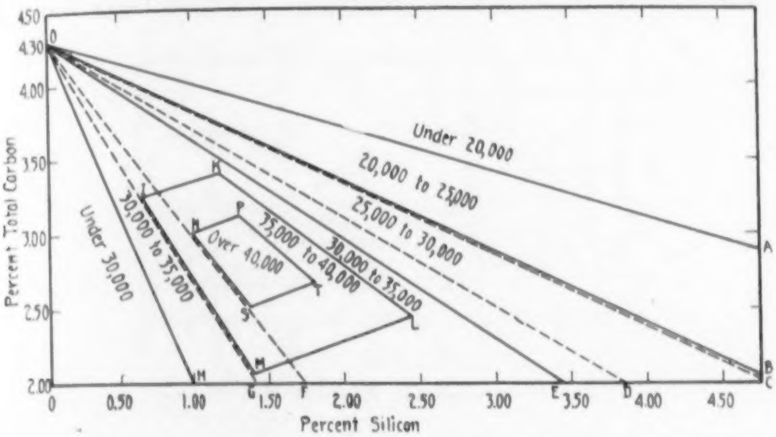


Fig. 2—Constitutional and Tensile Strength Diagram of Cast Iron.

ing temperature and the point of complete solidification. The method of determining this rate of cooling will be described later. The rate of cooling after solidification is retarded considerably due to the refractoriness of the mold and exothermic reactions which may take place as will be explained later.

Physical Properties

An extended search of the literature of cast iron and strength of materials revealed no instance where evidence of the presence of an elastic limit existed. Most of the stress-strain diagrams published refer to ordinary gray iron. Since the elastic properties of a material govern the permissible working stresses, it was decided to investigate this field. Fig. 3 shows the stress-strain diagrams both in tension and compression of cast iron of the following composition:

	Per Cent
Total Carbon	3.36
Manganese	0.45
Phosphorus	0.26
Sulphur	0.163
Silicon	1.29
Brinell Hardness Number	187

These diagrams are representative of many obtained and show that the type of material given possesses a true elastic limit at approximately 8000 pounds per square inch in tension and 45,000 pounds per square inch in compression. It will be perfectly safe to use a working stress in tension of 6000 or 7000 pounds per square inch and 40,000 pounds per square inch in compression with this class of material. These tests have shown

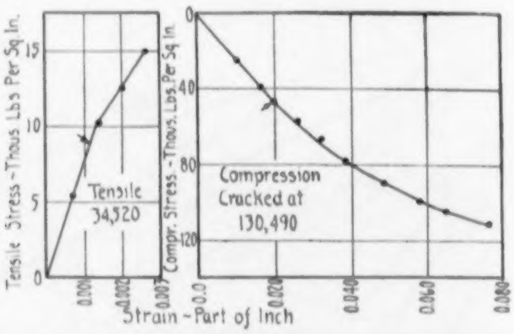


Fig. 2—Stress-Strain Relations of Cast Iron.

that cast iron possesses a modulus of elasticity of 20,000,000 in tension and 30,000,000 in compression. Due cognizance should be taken of this fact in proper design. In all authoritative works on strength of materials and machine design inspected it was assumed that the modulus of elasticity in tension and compression were the same. It is evident that transversely loaded members designed on this premise will be in error because the neutral axis instead of corresponding to the geometrical axis of such a member will be located between the geometrical axis and the surface in tension.

The following range of composition which has given good results in Diesel engine manufacture and performance can be readily melted in a cupola with uniform results and give a minimum tensile strength of 35,000 pounds per square inch.

	Per Cent
Total Carbon	2.95 to 3.20
Manganese	0.30 to 0.50
Phosphorus	under 0.20
Sulphur	under 0.12
Silicon	1.00 to 1.30

This composition has been specified at the New York Navy Yard for three different types of Diesel engine castings with com-

plete success both in fabrication and in service. The minimum tensile strength obtained during the past nine months was above 36,000 pounds per square inch. This composition is not adaptable to green sand casting with wall thicknesses below 7/8 inch. Thinner walled castings must be cast in dry sand in order to prevent chilled corners or surfaces. Three unusual features of

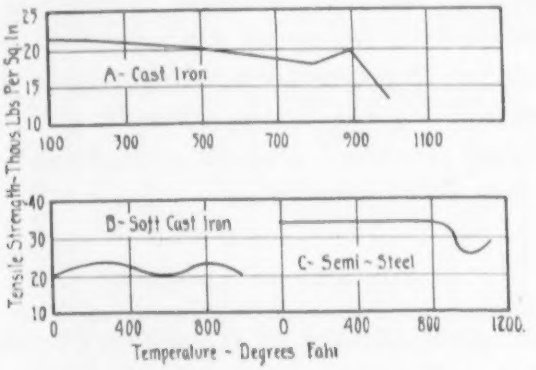


Fig. 4—Strength of Cast Iron at Elevated Temperatures.

this composition are noticeable: (A) low manganese, (B) low phosphorus, (C) low silicon.

The above composition has been found to best satisfy the following requirements: (1) strength at elevated temperatures, (2) elimination of porosity, (3) maximum resistance to wear, (4) minimum growth due to repeated heating.

Fig. 4, curves A and B for gray iron shows that the tensile strength holds up well up to 900 degrees Fahr. (482 degrees Cent.). Curve C shows that semi-steel or high grade cast iron acts in the same manner. Curves B and C are reproduced from an article by Bregowsky and Spring.[2] The temperatures of certain portions of a Diesel engine are appreciably elevated under working conditions, in spite of the fact that these parts are cooled. The temperatures vary from room temperature to 630 degrees Fahr. Also the uneven distribution of temperature causes stresses to develop which must be taken into consideration. Hence, if the weights of Diesel engine parts are to be kept as low as possible, it is necessary to use the highest grade of material procurable. The fact must also be kept in mind that these temperatures may be augmented because of occasional disarrange-

[2]Bregowsky and Spring, International Association for Testing Materials, 1912.

ments such as clogging of cooling passages. In such cases some portions may reach 900 or 1000 degrees Fahr. (482 to 538 degrees Cent.). The ordinary maximum working pressure in the working cylinders of a Diesel engine is 600 pounds per square inch, and may accidentally reach 750 pounds per square inch. In air compressors used in conjunction with Diesel engines the working pressure in the high pressure cylinder is generally 1000 pounds per square inch for spray air injection, and 2500 pounds per square inch for charging air starting flasks. Hence, not only is the requirement of great tensile strength obvious, but castings used for working cylinders and air compressor cylinders must be absolutely free from porosity.

Porosity of Castings

There are a great number of factors which may cause a casting to be porous. However, assuming a casting to be properly gated and fed by risers, the general concensus of opinion has been that the lower the phosphorus the less should be the tendency for porosity to develop. This opinion is feasible because the iron phosphide eutectic which solidifies at 1670 degrees Fahr. (910 degrees Cent.) is the last portion of a casting to solidify. The tendency always is that the constituent of lowest melting point tends to segregate near the center of the last portion to solidify, that is, near the center or the middle of the thickest portion of a casting of uneven thickness. Observation over a long period of time has indeed justified the conclusions drawn. Castings containing about 0.60 per cent phosphorus, and which had shown porous spots, although cast in identically the same manner and at the same temperatures, were absolutely sound when the phosphorus was reduced below 0.20 per cent. This is possible by the use of low phosphorus pig iron in the charging mixture. However, iron mixtures low in phosphorus are rather sluggish and it is necessary to use higher pouring temperatures. The pouring temperature of the aforementioned composition should be above 2600 degrees Fahr. (1427 degrees Cent.). If a casting is so designed that it is not possible to feed a heavy section by means of risers after surrounding portions of thinner wall thickness have set, no means or trials conceivable by the foundryman can make such sections solid.

Resistance to Wear

A series of tests were conducted to determine the relative resistance of cast iron to wear. The test was conducted by rotating a cylinder 6 inches in diameter by 6 inches long. This cylinder was keyed on the arbor of a lubrication testing machine. A block $3 \times 4 \times 1\frac{5}{8}$ inches with one 3×4 inch surface curved to fit against the curved surface of the cylinder was held

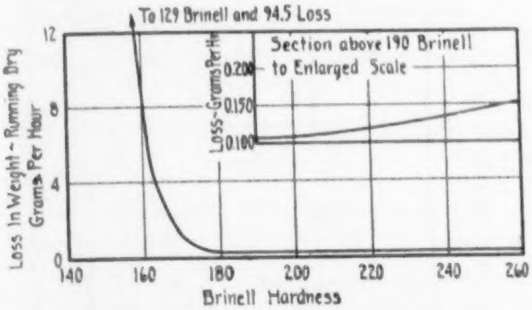


Fig. 5—Relation of Brinell Hardness to Wear of Cast Iron.

stationary against the cylinder. Considerable preliminary work was performed to determine the proper degree of loading and lubrication. This data was compared with similar material which had been installed and run in service. It was found that the two surfaces rubbing together under a 50-pound load (the area of contact was 9 square inches) and without lubrication, would give a short-time test which would compare with service results, that is, the material which showed the least amount of wear by this test, would give maximum length of life in service. Fig. 5 is a diagram constructed from the tests of fifteen different grades of cast iron. It is noteworthy that all of the results fell exactly upon the curve shown. The materials tested covered a wide range of composition from low carbon and low silicon to high carbon and high silicon. The tests show conclusively that the controlling factor for resisting wear is Brinell hardness. Ferritic irons wear down extremely rapidly. Iron between 180 and 210 Brinell hardness, which corresponds to a pearlitic matrix offers greatest resistance to wear. Iron containing above the eutectoid proportion of combined carbon wears down slightly faster, but not much. It is probable that some particles of iron carbide break out and act as a sharp abrasive.

Rugan and Carpenter[8] carried out an extended investigation of the phenomenon of growth of cast iron due to repeated heating. It was found that a series of alloys of practically pure iron with varying percentages of carbon showed only a small increase in volume and a small gravimetric increase after repeated heating at various temperatures. It was also stated that the phenomenon

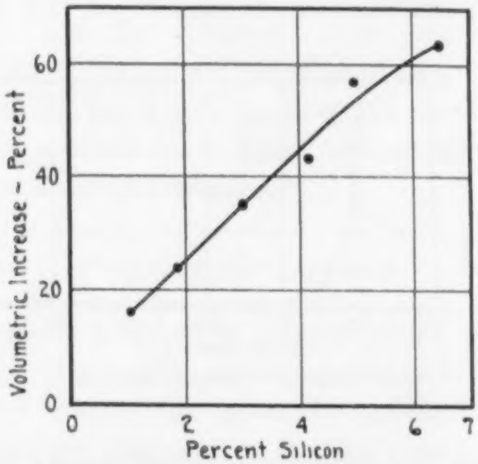


Fig. 6—Curve Showing Growth of Cast Iron with Increasing Silicon Content.

commences at about 1200 degrees Fahr. (649 degrees Cent.), and occurs with maximum rapidity at 1345 degrees Fahr. (729 degrees Cent.). Another series of tests was made using iron with practically constant carbon content (3.4 to 4.0 per cent) but with silicon varying from 1.0 to 6.0 per cent. In each case more than 3.3 per cent carbon was precipitated in the graphitic form before the test was made. The results are shown in Fig. 6. It is clear that the lower the silicon content the less the amount of growth due to repeated heating. More recent research indicates that growth commences at temperatures as low as 930 degrees Fahr. (499 degrees Cent.) and in the presence of superheated steam and flue gases, as low as 800 degrees Fahr. (427 degrees Cent.). Since the normal working temperatures in a Diesel engine exceed 600 degrees Fahr. (316 degrees Cent.) in some portions it is possible that if proper circulation of the cooling medium is retarded, temperatures above that at which growth begins, may occur. For this reason, it is advisable to use iron with silicon

[8]Rugan and Carpenter, *Journal*, Iron and Steel Institute, 1919.

as low as possible as a preventative measure. At the present time it is considered that growth is caused by expansion of graphite flakes due to the absorption of gases by the flakes. Silicon acts

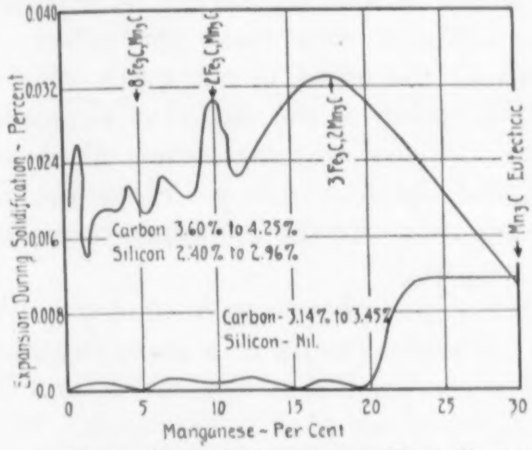


Fig. 7—Effect of Manganese on Linear Expansion of Cast Iron During Solidification.

as a precipitant of graphite. By precipitating large quantities of graphite high silicon is probably the primary cause of growth.

The choice of low manganese as mentioned before, is justified

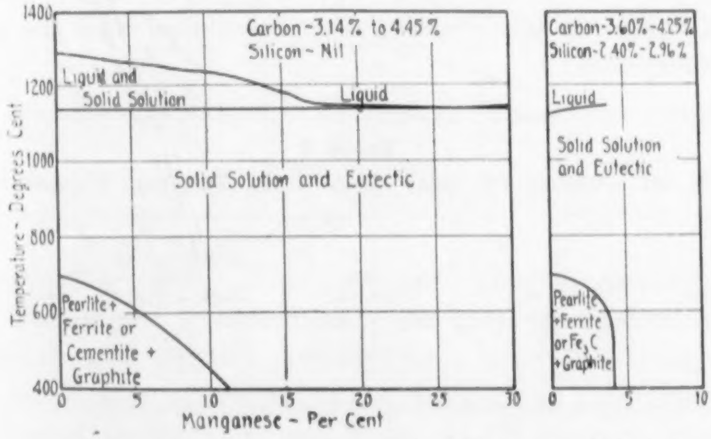


Fig. 8—Effect of Manganese on the Constitution of Cast Iron.

by the following data. Fig. 7 shows the relative expansion during solidification of two types of cast iron, one with practically no silicon and one with high silicon, both with varying percentages of manganese.[4] It will be noticed that between 0.75 and 1.25 per cent manganese, in the presence of silicon, a decided increase

[4]H. I. Coe, *Engineering*, Vol. 90, p. 581, 1910.

in expansion occurs during solidification. Fig. 8 shows a portion of the equilibrium diagrams constructed by the author from Coe's data. An inspection of these two figures would indicate that the presence of small percentages of the double carbide of manganese and iron ($8Fe_3C, Mn_3C$) may cause this effect. However, the exact mechanism of the effect is not quite clear. Nevertheless, cognizance must be taken of the fact that a majority of castings containing about 1.00 per cent manganese developed cracks similar to those called sulphur cracks. Since the range of manganese content was reduced (the last three years) not one case of this defect has occurred.

The use of low phosphorus with comparatively low carbon and low silicon naturally results in a more sluggish metal in the molten state. The combination of low carbon and low silicon also means a higher point of complete liquefaction. For these reasons higher casting temperatures than ordinarily used in gray iron practice are necessary. An extended series of experiments were conducted to establish the relation between pouring temperature, wall thickness and structure of the metal. O. Smalley[5] discussed the cooling curves of various sizes of cubes of cast iron. From his data the rate of cooling from the pouring temperature to the point of complete solidification was calculated and the following table constructed:

Table I
Rate of Cooling of Gray Iron from Pouring Temperature

Size Cube	Area, Sq. In.	Vol., Cu. In.	Cooling Rate Through Solidification Zone Degs. Per Min.	Cool. Surface Sq. In., Per Cu. In. Volume
4	96	64	12.0	1.5
6	216	216	4.0	1.0
8	384	512	2.2	.75

It was decided to continue this work and in consequence four series of tests were conducted. In the first two experiments three bars were cast, one each of the following sizes: ½, 1, and 2 inches square and all 6 feet long. An 18-inch down gate was used at one end and an 18-inch up gate at the other end. The down gate and riser were the same size as the bar in each case. The second

[5]O. Smalley, International Foundrymen's Convention, Paris, 1923.

set was poured at a higher temperature than the first set. Table II and III show the data obtained.

Table II

Size Bar, Inches	Area, Sq. In.	Temp. at Cupola	Pouring Temp.	Time to Pour	Ft. Traveled	Rate Flow, Cu. In. Per Sec.	Cooling Surface Sq. In., Per Cu. In. Vol.
½	0.25	2767	2580	3.5	4.0	3.43	8
1	1.00	2767	2580	5.0	9.5	22.8	4
2	4.00	2767	2580	2.2	9.0	220.0	2

Table III

Size Bar, Inches	Area, Sq. In.	Temp. at Cupola	Pouring Temp.	Time to Pour	Ft. Traveled	Rate Flow, Cu. In. Per Sec.	Cooling Surface Sq. In., Per Cu. In. Vol.
½	0.25	2767	2663	3.0	9	9	8
1	1.00	2767	2663	6.0	9	18	4
2	4.00	2767	2663	2.4	9	160	2

The half inch bars were chilled throughout and the one poured at 2580 degrees Fahr. (1416 degrees Cent.) only traveled 48 inches when the leading end had completely solidified and

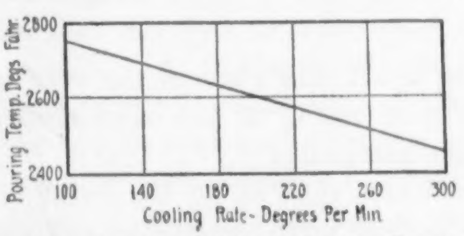


Fig. 9—Relation Between Pouring Temperature and Cooling Rate.

prevented further flow. This test gave the key to the rate of cooling. The 1 and 2 inch bars were gray throughout and the 2 inch bar showed slightly coarser grain than the 1 inch bar.

The other sets of experiments were then conducted. One set was poured at 2490 degrees Fahr. (1366 degrees Cent.) and the other set at 2750 degrees Fahr (1510 degrees Cent.). Fig. 9 shows the relation between the pouring temperature and the rate of cooling for the bar ½ inch square. When the cooling area per cubic inch of volume is plotted against the cooling rate, an exponential function is obtained. However, if this same curve is plotted with logarithmic co-ordinates the graph will be a straight line. The equation for Smalley's data (taken on high silicon

iron) has been plotted in this manner on Fig. 10. The four equations for the low carbon low silicon iron are also plotted on Fig. 10. This chart shows two important facts:

(1) A reduction of silicon tends to shift any graph to the right; that is, to increase the rate of cooling through the solidification zone thereby increasing the tendency to chill.

(2) An increase in pouring temperature shifts any graph

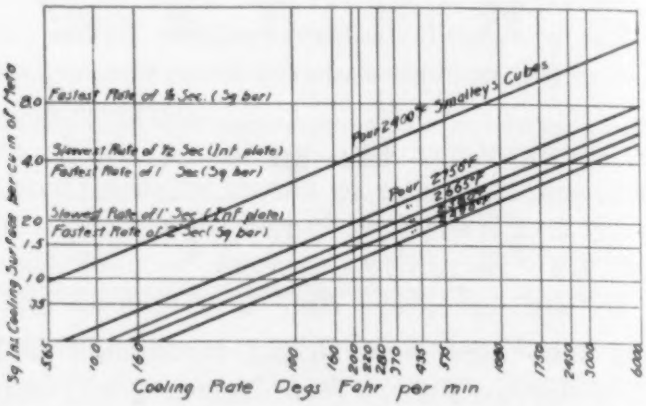


Fig. 10—Relation Between Cooling Surface, Pouring Temperature and Cooling Rate of Iron Castings (Composition in Text).

to the left on the chart and reduces the rate of cooling through the solidification zone acting in the same manner as an addition of silicon, but less markedly.

This data indicates that up to the point of solidification the tendency of the carbon is to remain in the combined state and that the separation of carbon occurs after solidification, and is controlled by composition and time. For the same composition the rate of cooling can be retarded by varying the pouring temperature and the precipitation of carbon effected thereby. Also, for the same temperature the precipitation of graphite can be effected by adjusting the silicon content. The fracture of the one inch bar cast at 2665 degrees Fahr. (1463 degrees Cent.) was considered as the most desirable and from Fig. 10 the maximum rate of cooling through the solidification zone is 1750 degrees Fahr. (954 degrees Cent) per minute. This rate may seem high and that an effect of quenching to 800 degrees Fahr. (427 degrees Cent.) would be obtained. As before mentioned, by the rate of cooling is meant the rate at which the metal cools from

the casting temperature to the point of complete solidification. Between these points the metal is subjected to a quenching action. A considerable quantity of heat is absorbed by the sand of the mold to a shallow depth. This brings the sand to the same temperature as the metal. But sand is refractory in character and from a point slightly below the point of complete solidification, the rate of cooling is much slower.

Heat Treatment of Cast Iron

The heat treatment of cast iron is a field which has hardly been touched. Probably because the full possibilities of cast iron have not been fully realized until quite recently. The possibility of producing cast iron with a tensile strength greater than 50,000 pounds per square inch has created a new interest in this material and its uses. It is no longer a low priced commodity of indifferent application, but a true engineering material of value. These possibilities awaken new interest in its applicability.

Research in the field of heat treatment of cast iron has been meager, although a few instances have come to the author's attention where heat treatment of cast iron has been of value. A producer of automobiles resorted to quenching cast iron brake bands with good results. A producer of machine tools case-hardened parts of machinery, such as latches and trips.

Annealing is the simplest of heat treating operations. It is applicable to cast iron for two reasons; (1) artificial aging, (2) softening. The object of artificial aging is to relieve stresses which were set up while the casting was cooling in the mold. If not relieved, these stresses will cause distortion after a casting is machined. Aging may, if carried out at high enough a temperature, also produce a small amount of growth and thus minimize the amount of distortion of working parts during service. An extended series of tests were conducted upon cast iron having a total carbon content of 2.2 to 3.5 per cent and a silicon content of 1.0 to 2.0 per cent which may be summarized as follows:

Annealing Temp. Deg. Fahr.	Time Hrs.	Reduction in Tensile Strength Pounds Per Square Inch
500	3	4000
700	6	7000
800	6	3000
900	4	1000
1000	5	5000
14000	3	7500

It is unfortunate that the data was not developed upon a more scientific basis, but the results represent several hundred tests. It will be noticed that the minimum reduction in tensile

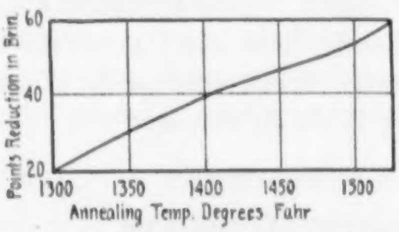


Fig. 11—Reduction in Brinell Hardness Caused by Annealing 1 Hour at Various Temperatures.

strength is at 900 degrees Fahr. (482 degrees Cent.). Service records have shown that no trouble has been encountered by annealing 4 hours at this temperature, that is, an aging process to

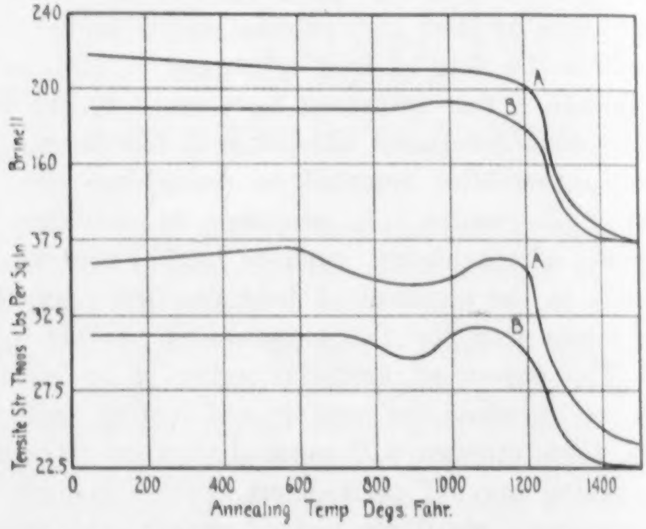


Fig. 12—Cast Iron Annealed 1 Hour and Furnace Cooled.

	A	B
Silicon	1.44	1.69
Sulphur	0.123	0.10
Manganese	0.68	0.55

prevent growth from repeated heating is effected as well as a relief of casting stresses with a minimum of reduction in tensile strength. The value of annealing as a softening treatment is shown in Fig. 11. This diagram was prepared for shop use. Brinell hardness limits have been specified for certain types of castings. These limits are 180 minimum and 210 maximum. If a casting showed a hardness of 250, the chart was referred to

and showed that annealing for one hour at 1475 degrees Fahr. (802 degrees Cent.) would reduce the hardness to about 200, which is within the specified limits. However, foundry practice has since been developed to such an extent that castings can be

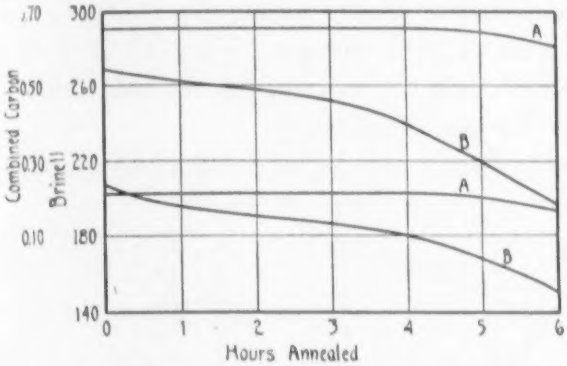


Fig. 13—Effect of Time of Annealing.

	A	B
Silicon	1.32	1.32
Sulphur	0.097	0.097
Manganese	0.59	0.59
Anneal Temp.	1050° F.	1150° F.

uniformly produced within the limits stated and recourse to heat treatment is seldom. Nevertheless, Fig. 11 served a useful purpose during the period of development.

Fig. 12 gives some results of tests conducted to show the effect of annealing at various temperatures on the tensile strength and Brinell hardness of two types of cast iron. This work was conducted by McPherran and Harper[6] at the Allis Chalmers Company in 1921. This diagram shows that:

(1) Iron containing 1.44 per cent silicon is unaffected by annealing at temperatures up to 1200 degrees Fahr. (649 degrees Cent.).

(2) Iron containing 1.69 per cent silicon is unaffected by annealing at temperatures up to 1100 degrees Fahr. (593 degrees Cent.).

(3) From these temperatures up to 1500 degrees Fahr. (816 degrees Cent.) tensile strength and Brinell hardness fall off progressively.

The general effect is that the lower the silicon content the higher the temperature of annealing, which causes an alteration in physical properties.

[6]McPherran and Harper, *Foundry*, May, 1923.

In Fig. 13 is shown the effect of annealing for various periods of time at two different temperatures on the Brinell hardness and combined carbon of cast iron suitable for Diesel engine castings. These tests were also conducted by McPherran and Harper. This diagram shows primarily that the process of annealing effects a structural change. Figs. 12 and 13 indicate that three factors enter into the annealing of cast iron; (1) temperature, (2) time, (3) composition.

A structural change can be effected at comparatively low an-

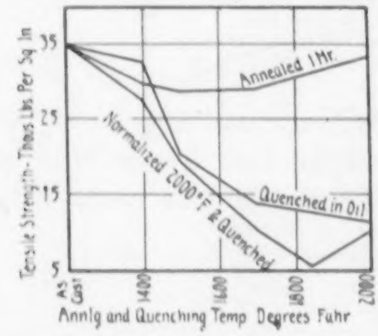


Fig. 14—Effect of Annealing, Quenching and Normalizing on Cast Iron.

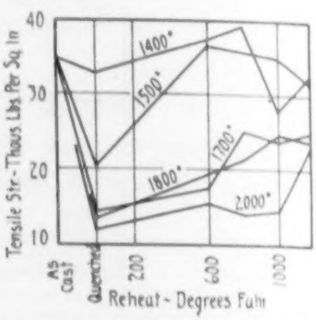


Fig. 15—Effect of Quenching (Oil) and Tempering on Cast Iron.

nealing temperatures if the material is held at heat long enough. Also, if the silicon is low, sufficiently elevated annealing temperatures can be used which will insure the relief of casting stresses without appreciable alteration of the physical properties.

The data so far presented embraces the field below 1500 degrees Fahr. (816 degrees Cent.). However, the investigation was extended to include higher temperatures. Tests were made upon material before mentioned as preferable for Diesel engine castings. The curve designated "annealed" in Fig. 14 shows that the tensile strength is reduced by annealing temperatures up to 1500 degrees Fahr. (816 degrees Cent.). This agrees with the data presented by McPherran and Harper. However, as the annealing temperature is increased above 1500 degrees Fahr. (816 degrees Cent.) the tensile strength increases. This is probably due to the fact that some graphite is re-dissolved and retained in the combined state. This same effect is shown by the annealing of high strength cast iron.

Fig. 14 also shows the effect of quenching in oil and normalizing and quenching in oil. As the quenching temperature is in-

creased the tensile strength falls off steadily up to 2000 degrees Fahr. (1094 degrees Cent.). Since the tensile strength after annealing at this temperature was nearly the same as in the "as cast" state, that temperature was chosen as the normalizing tem-

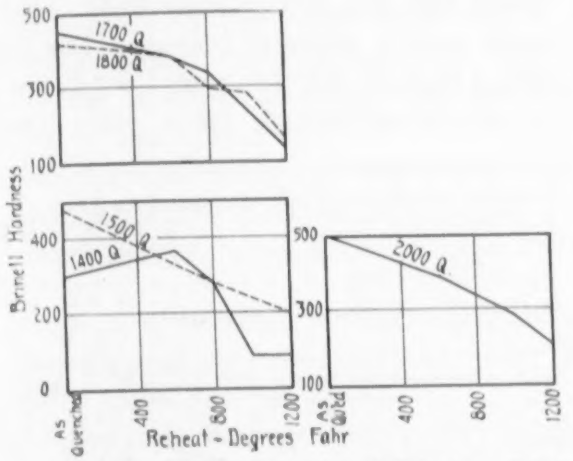


Fig. 16—Effect of Quench and Reheat on Brinell Hardness of High Grade Cast Iron.

perature. It is clear that normalizing and quenching has a similar effect to quenching but is more detrimental.

Fig. 15 shows the effect of reheating upon the tensile strength

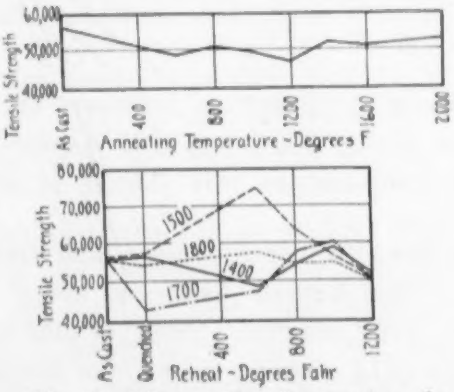


Fig. 17—Effect of Heat Treatment on the Tensile Strength of High Test Cast Iron.

of Diesel cast iron quenched at various temperatures up to 2000 degrees Fahr. (1094 degrees Cent.). The following facts are apparent:

(1) Reheating after quenching effects an augmentation of tensile strength.

(2) The higher the quenching temperature, the higher

the temperature of reheat required to produce the maximum augmentation.

(3) Quenching in oil from 1400 to 1500 degrees Fahr. (760 to 816 degrees Cent.) and reheating to between 600 and 800 degrees Fahr. (316 and 427 degrees Cent.) actually increases the tensile strength above that in the "as cast" condition.

(4) A structural change takes place progressively up

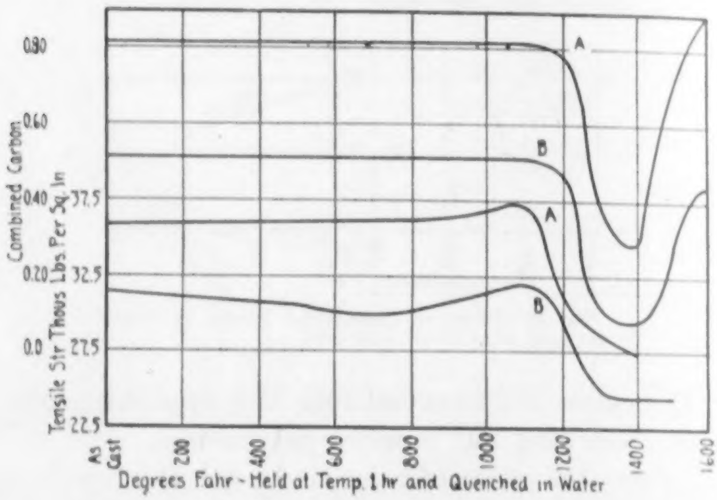


Fig. 18—Effect of Quench (Water) on Strength and Constitution of Cast Iron.

to some temperature between 1500 and 1700 degrees Fahr. (816 and 927 degrees Cent.). Above that temperature this change is complete.

Fig. 16 shows the effect of the same heat treatment upon the Brinell hardness. The Brinell hardness after quenching from 1400 degrees Fahr. (760 degrees Cent.) is 300 and by reheating to 600 degrees Fahr (316 degrees Cent.) the hardness is increased to 370. When reheated to about 800 degrees Fahr. (427 degrees Cent.) the hardness falls to a low figure. The hardness after quenching from 1500 degrees Fahr. (816 degrees Cent.) was 480 and fell off at a uniform rate by reheating at various temperatures up to 1200 degrees Fahr. (649 degrees Cent.). The hardness after quenching from temperatures above 1500 degrees Fahr. (816 degrees Cent.) is quite uniform, varying from 420 to 440. The variation due to reheating is also quite uniform. It is ap-

parent that some structural change occurs in the range above 1300 degrees Fahr. (705 degrees Cent.). What this change is has not been determined, but it is expected that microscopic examination which has only just begun will shed some light as to its nature.

Fig. 17 shows the effect of quench and temper on the tensile strength of special high strength cast iron. It is evident that the field below 3.00 per cent total carbon is a fertile one for investigation and gives promise of interesting developments especially with regard to heat treatment.

Fig. 18 shows the variation of tensile strength and combined carbon with quenching temperature in the field below 1600 degrees Fahr. (871 degrees Cent.). The following facts are apparent:

(1) There is apparently no appreciable effect caused by quenching from temperatures below 1100 degrees Fahr. (594 degrees Cent.).

(2) Above 1100 degrees Fahr. (594 degrees Cent.) a structural change occurs. The combined carbon decreases to a minimum at 1400 degrees Fahr. (760 degrees Cent.) with a corresponding decrease in tensile strength.

(3) As the quenching temperature increases above 1400 degrees Fahr. (760 degrees Cent.) another structural change occurs. The combined carbon increases.

(4) In the field above 1400 degrees Fahr. (760 degrees Cent.) the structural changes occur with greater magnitude, the lower the silicon.

From the data presented it is evident that a new period of activity as regards the production and applicability of cast iron is in view. It is apparent, though, that while there is a possibilty of value in the heat treatment of cast iron, considerable research remains to be done. Research in this field should be directed toward compositions of cast iron with lower carbon and silicon than has been usually produced in the past.

THE DEVELOPMENT OF SCIENTIFIC RESEARCH AND ITS APPLICATION TO INDUSTRY

By T. McLean Jasper

Abstract

The author of this paper points out the qualifications which are necessary for a successful research worker. The general field of scientific research as applied to engineering problems is divided into three divisions. Methods of attack of a research problem are shown. After a research problem is solved there are many new problems for the management of a manufacturing company to confront before it can exploit the fruits of the successful research. When a successful organization with mental, physical and financial equipment exists, the results of successful research and its application to industry become a public benefit and those engaged in it are public benefactors.

THE development of scientific research and its application to industry is a problem which not only confronts the research worker, but involves in addition the economical introduction of the advantageous results obtained by research into the processes of manufacturing and marketing. The solutions to the problems of production and marketing are often neglected, and, in consequence, the application of successful research does not bring forth anywhere near the economies which should have been obtained.

Often undesired results in the application of research are brought about by the fact that it is attempted before the work of the laboratory or study is sufficiently completed to draw a sane and unbiased conclusion. Sometimes the cause of unsuccessful application of research is the result of biased data on which unsound conclusions have been based.

The development of scientific research is occasionally confused with the making of tests. Research involves much more than the making of tests. It involves the logical planning of experiments which when completed will give a yes or no answer to a definite question. Such experiments must be carefully carried out and a correct interpretation of the results obtained. The expenditure

A paper presented before the Spring Sectional Meeting of the Society, Milwaukee, May 19 and 20, 1927. The author, T. McLean Jasper, is director of research for the A. O. Smith Corporation, Milwaukee.

of much patience and the application of much energy and thought are often necessary. A thorough understanding of the fundamental principles underlying the manufacturing processes to which it is to be applied and the marketing condition with which it has to compete are usually essential.

Few men are so constituted as to successfully carry through a research problem. In general, research workers desire to arrive at a solution too quickly or set out to find a preconceived answer to a problem and give weight only to the work which seems to favor the answer desired. The work resulting from such an attitude often produces an incorrect result. Investigators must be willing to disregard entirely a set of tests laboriously obtained and start all over again when it is really demonstrated that they do not apply in answering the question. Some will take no pains to study and present the negative answer to a problem when such is found.

Successful research, therefore, is a matter of thoroughly understanding a problem, outlining a logical attack, carrying through in a painstaking manner the necessary tests and analyzing honestly the results to produce the correct answer.

The general field of scientific research as applied to engineering problems can be divided into three general divisions.

Research leading to discoveries.

Research leading to new and more economical methods of producing old products.

Researches tending to supplement and improve old processes and products.

Of the three divisions outlined above, the first generally requires a higher degree of skill and application than the other two because less precedent is available. In the other two divisions the skill required in general decreases in the order named.

Scientific research is subservient to rules and principles well within the capacity of the human mind and energy. The most important mental equipment that a research worker can have is—

(a) A thorough understanding of the general laws of nature.

(b) Ability to apply analogy and analysis.

(c) Patience, diligence and care in the use of sensitive instruments and equipment.

(d) A good sense of proportions and ability to cooperate.

Good equipment and sufficient funds to proceed with work are extremely important. Successful research when economically applied creates funds by which its future can be assured.

The methods of attack in research can be divided into three general heads.

(a) A study of the work of others on similar or analogous problems and of the principles underlying the particular problem involved.

(b) The performance of preliminary tests which tend to develop a sense of the problem in hand.

(c) The carrying out of the fundamental investigation which has been designed to give answer to the questions asked.

Too much stress cannot be placed on studying the work of other reliable investigators on similar or analogous problems. Such publications as The Proceedings of the Royal Society, of the various National Academies of Science and of Professional Societies, the Philosophical Magazines and other Technical papers and magazines are particularly helpful. These are available in the various libraries in the country. This preliminary study tends to develop a sense of proportion for the thing in mind.

The writer knows of repeated instances where research workers have gone through the steps taken by other investigators and actually performed indentically similar tests in order to be able to interpret the work thoroughly, and to realize what was involved, trying at the same time not to lose sight of the larger possibilities in the problem. It has been clearly demonstrated that, by such methods, the most fruitful work has developed.

The study of the work and life of successful scientific research workers has been a method which has repeatedly stood out as a preliminary training to the success of other research workers.

When the problem has been successfully solved, the next thing to do is to present the work in such a manner that it will be readily understood by those who can best use it. In order that the results of successful investigation may be used in industry it is frequently necessary to hand them over to an entirely separate organization for their successful application.

When the time becomes ripe for application a new group of problems appear and the handling of the situation often assumes an entirely different aspect.

There are three important points which need be considered in the question of applying changes to manufacturing processes, i. e.

A consideration of its effect on the existing economic situation.

A consideration of its cost.

A consideration of its application with the class of workers which are involved in the change.

To draw attention to these factors may seem unnecessary, yet the fact remains that the lack of a full consideration of them has resulted repeatedly in failure and the waste of much money. Cases can be cited in which the above statements can be verified and insufficient attention to them has held valuable discoveries from early fruition.

The problems confronting the management of a manufacturing company in producing and successfully exploiting the fruits of successful research work are many and varied and much depends on the loyalty and cooperation of the personnel of the staff and workers.

When all these points have been considered, the next steps are:

(a) A preliminary development of mechanical methods for applying the results of research.

(b) The application of such development work to production methods and routing it through the plant.

(c) A study of the best methods of buying and marketing.

A careful economical solution of the above outline has a very direct bearing on the financial return and will determine the degree of success of the venture.

Too little attention is sometimes paid to the question of preliminary development and often the process of manufacture is saddled with uneconomical manufacturing expenses which after expenditure of considerable sums of money are difficult to overcome.

A careful solution of the market situation allows for an analysis of the needs for development work and protects the company from heavy unnecessary expenditures or on the other hand, from expenditures on a meager scale which curtail freedom in pushing the matter to the most successful conclusion. By the

(Continued on Page 491)

CASE CARBURIZATION OF PRODUCTION STEELS BY MEANS OF SALT BATHS OF LOW CYANIDE CONCENTRATION

By H. B. Northrup

Abstract

This paper describes a series of carburizing tests made on three different types of steels by means of a molten sodium cyanide bath maintained at a temperature of 1650 degrees Fahr. Photomicrographs and graphs showing the penetration of carbon are presented.

The paper points out that a thorough study has been made by others of the characteristics of steels treated in cyanide mixtures at temperatures up to 1500 degrees Fahr., through which range there seems to be an embrittling effect due to nitride absorption whereas at a temperature of 1650 degrees Fahr., brittleness is largely eliminated.

IN the presentation of this paper, no claims are being made to any new discoveries in the art of case carburizing steel by the employment of a molten cyanide bath. The object is, rather, to furnish definite and accurate data which may be of value to those interested in heat treating steels by such methods. Attention has not been directed toward the amount of nitrogen absorbed by the steel at the temperatures involved but has rather been directed toward the amount of carbon introduced into the steel through the medium of a bath carrying both carbon and nitrogen. The effect of the nitrogen element of a cyanide bath has been thoroughly covered by many previous investigators,[1,2,3,4] which investigations have been competently summarized in a paper presented before this society.[5]

[1] "Effect of Different Mixtures of Cyanide Hardness and the Role of Nitrogen in the Process," V. E. Hillman, Transactions, American Society for Steel Treating, January, 1922, pp. 296.

[2] "True Action of Cyanide in Case Hardening Steel," G. R. Brophy and S. B. Leiter, Transactions, American Society for Steel Treating, March, 1921, p. 330.

[3] "The Reactions and Effects of Nitrogen on Steel," C. B. Sawyer, Transactions, American Society for Steel Treating, September, 1925, p. 291.

[4] "Cyanide Brittleness," V. E. Hillman and E. D. Clark, Transactions, American Society for Steel Treating, December, 1926, p. 954.

[5] See foot note 3.

A paper presented before the spring sectional meeting of the Society, at Milwaukee, May 19 to 20, 1927. The author, H. B. Northrup, is metallurgist with the J. W. Kelley Company, Cleveland.

In all of the investigations noted, the carburization of steel by means of sodium cyanide was not carried on at temperatures above 1500 degrees Fahr. and there is no doubt but what the effects of nitrogen at temperatures up to 1500 degrees Fahr. have been thoroughly covered. The practice covered in the present paper deals with temperature ranges up to 1650 degrees Fahr. and a prerequisite of the production steels so carburized was the elimination of brittleness. Hence it is believed that under the conditions of this paper the embrittling effect of nitrogen is nil.

Where steel is subjected to the carburizing action of sodium cyanide at an elevated temperature, the sodium cyanide breaks up under heat, liberating carbon monoxide gas, (CO) which is free in the bath and at liberty to unite with the steel. The result of this union is the breaking up of the carbon monoxide gas molecule (CO) into carbon (C) and oxygen (O) with the result that the then red hot steel absorbs the carbon with the formation of iron carbide or cementite of the formula Fe_3C, and the evolution of oxygen. It has been proven, under production conditions, that the concentration of cyanide in the bath necessary to produce carburization under the conditions given is only 10 per cent NaCN, the remainder of the cyanide being dissipated by volatilization.

Previous papers on the subject have shown that the maximum carbon concentration in the case of a piece of cyanided steel is about 0.65 per cent carbon. No direct data has hitherto been available on the effect of carburizing by means of cyanide baths, steels of various analyses. It is then the purpose of this paper to present the data obtained by the carburization of three different classes of steel at a constant temperature by means of a low cyanide concentration salt bath.

The steels selected were of three common varieties suitable to carburization and for purposes of testing and ease of designation were called A, B, and C.

The analyses (Table I) were obtained on laboratory samples at the time the steel was accepted and do not represent the analysis of the actual bar from which the test pieces were obtained; hence any apparent discrepancy in final carbon determination hereafter given.

One bar of each of the above steels was cut up into six equal

Table I
Analysis of Steels

Class	Mark	C	Mn	P	S	Ni	Cr	Diam., Ins.
S. A. E. 1120	A	0.231	0.75	0.011	0.09	...	...	0.469
S. A. E. 2315	B	0.154	0.61	0.013	0.019	3.54	...	0.441
S. A. E. 3115	C	0.176	0.52	0.013	0.017	1.28	0.60	0.404

6-inch lengths making 18 pieces in all on the test. They were center-drilled and placed on the lathe where enough of the surface was removed to just clean up the piece, making it free from dirt, surface defects, etc., and presenting a clean surface to the action of the cyanide bath. Each piece had a $\frac{1}{16}$-inch hole drilled through one end to which was attached a wire to facilitate removal from the bath. The other end of the wire carried a metal tag with the designating numbers stamped thereon. The bars were thus designated as:

$$A_1, A_2, A_3, A_4, A_5, A_6$$
$$B_1, B_2, B_3, B_4, B_5, B_6$$
$$C_1, C_2, C_3, C_4, C_5, C_6$$

The cyanide bath into which the bars were placed was one which handled the regular production steels, was oil-fired and was heated to a temperature of 1650 degrees Fahr. The bath analyzed 23.2 per cent NaCN at the time the pieces were inserted. All 18 pieces were placed in the bath at one time in order to eliminate any temperature variation differences which might exist should the pieces be run separately at different times.

At the end of 1, 2, 3, 4, 5, and 6 hours, one piece of each of the steels was removed from the bath and allowed to cool in the air. Thus the pieces marked 6 were given a 6-hour immersion in a cyanide bath at a temperature of 1650 degrees Fahr. The NaCN content of the bath was kept constant during the run by exercising a standard practice of adding to the bath nine ounces of 73/76 per cent NaCN per hour. Thus at the completion of the test the bath analyzed 23.0 per cent NaCN.

After all the pieces were removed from the bath and had become cold, they were washed in boiling water to remove the last traces of the salt bath. They were then annealed in sand at 1350 degrees Fahr. and allowed to cool in the furnace. When cold they were cleaned by pickling in boiling sulphuric acid, washed, and wiped dry.

Next, each bar was placed on its original center in the lathe and a sufficient number of successive cuts of 0.005-inch per cut were taken to insure turning off all the case. Each cut was then analyzed for carbon and to insure against carbon entering the successive turnings from the lathe tool, a Stellite tool was used throughout for all turning operations. Each successive turning was bagged and analyzed for carbon until two successive turnings showed that the carbon content was within the range of the original steel, as represented by the core. (See Table II for analytical results)

Table II

Chemical Analysis on Consecutive 0.005-inch Cuts of Each Bar of Each of Three Different Steels

(Per Cent Carbon per Cut)

Cut No.	Depth, Inches	A1	A2	A3	A4	A5	A6
1	0.005	0.464	0.589	0.628	0.628	0.615	0.625
2	0.010	0.355	0.545	0.600	0.600	0.600	0.623
3	0.015	0.272	0.436	0.491	0.574	0.525	0.620
4	0.020	0.218	0.364	0.385	0.532	0.477	0.576
5	0.025	0.191	0.288	0.350	0.423	0.420	0.478
6	0.030	....	0.273	0.328	0.333	0.356	0.443
7	0.035	....	0.194	0.309	0.284	0.305	0.396
8	0.040	....	....	0.278	0.276	0.290	0.290
9	0.045	....	....	0.196	0.191	0.216	0.267
10	0.050	....	....	....	....	0.194	0.188
		B1	B2	B3	B4	B5	B6
1	0.005	0.376	0.500	0.525	0.564	0.565	0.565
2	0.010	0.284	0.450	0.484	0.505	0.505	0.508
3	0.015	0.254	0.330	0.380	0.464	0.461	0.465
4	0.020	0.232	0.306	0.330	0.352	0.371	0.377
5	0.025	0.155	0.155	0.155	0.303	0.358	0.366
6	0.030	....	....	....	0.158	0.330	0.303
7	0.035	....	....	....	....	0.185	0.248
8	0.040	....	....	....	....	0.153	0.163
		C1	C2	C3	C4	C5	C6
1	0.005	0.388	0.595	0.620	0.620	0.620	0.623
2	0.010	0.368	0.497	0.550	0.579	0.593	0.570
3	0.015	0.279	0.429	0.491	0.498	0.467	0.535
4	0.020	0.202	0.309	0.328	0.358	0.435	0.495
5	0.025	0.169	0.213	0.306	0.265	0.402	0.396
6	0.030	....	0.164	0.235	0.237	0.336	0.284
7	0.035	....	....	0.164	0.161	0.273	0.268
8	0.040	....	....	....	....	0.207	0.234
9	0.045	....	....	....	....	0.164	0.166

A study of these analyses show: (1) that the maximum carbon concentration in the case of any of the three steels is not over 0.628 per cent carbon in the time covered; (2) that the order of maximum carbon concentration for the three steels studied is A, C, B; (3) that the maximum carbon concentration

in the case was attained after three hours immersion; and (4) that additional time only served to increase the depth of case.

These findings are represented graphically in the curves shown in Fig. 1 in which percentages of carbon are plotted as ordinates and successive 0.005-inch cuts as abscissae.

After the carbon turnings had all been made, the dog end of each bar was prepared for photomicrographic investigation.

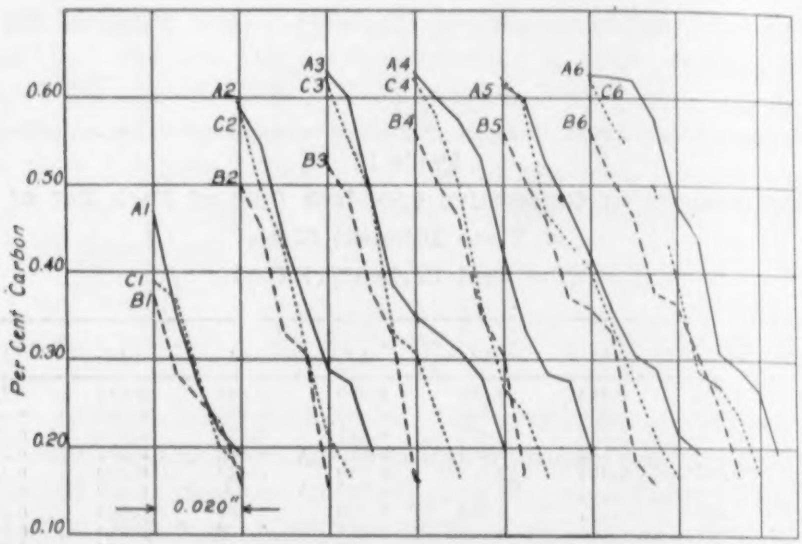
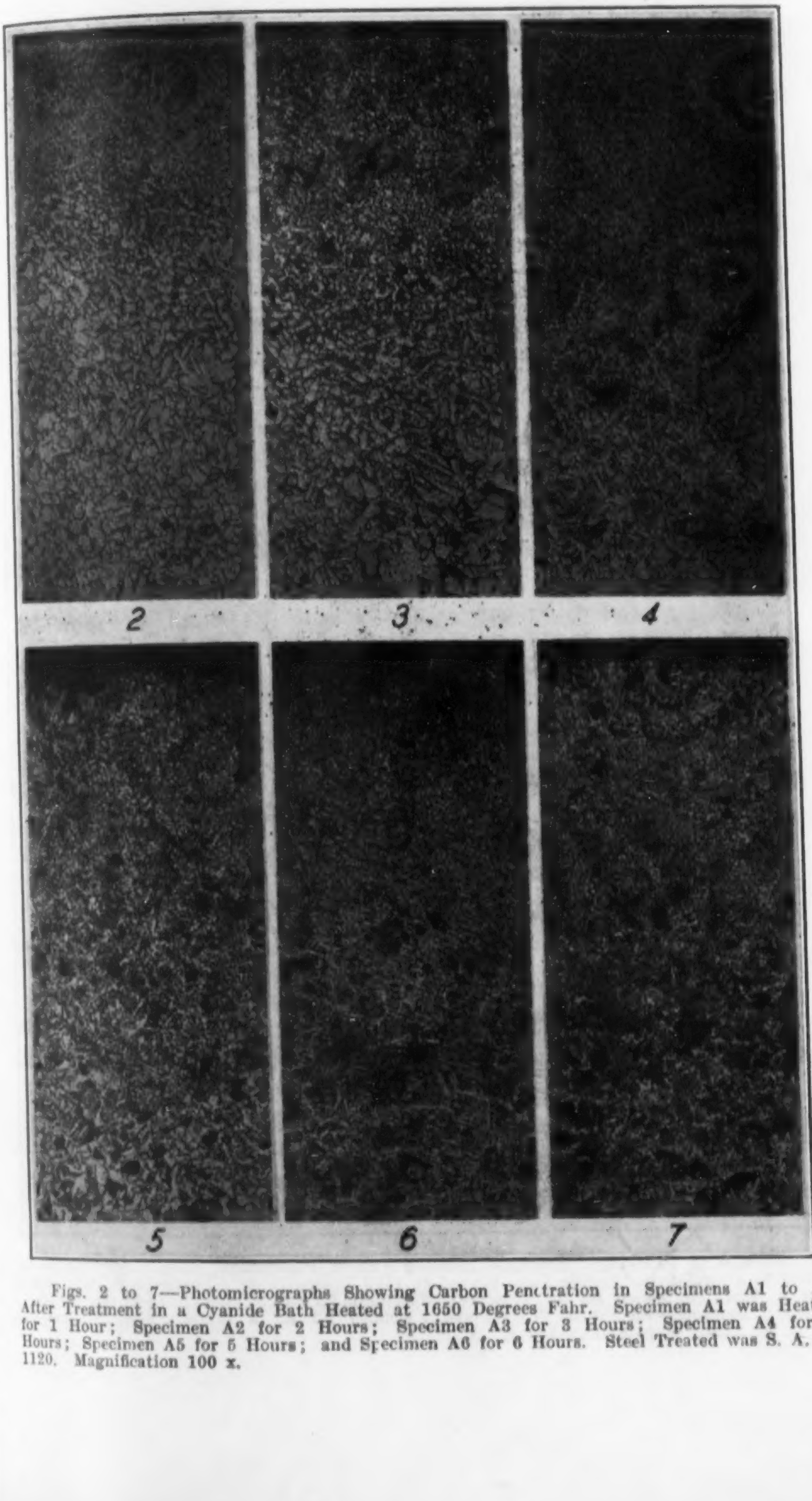


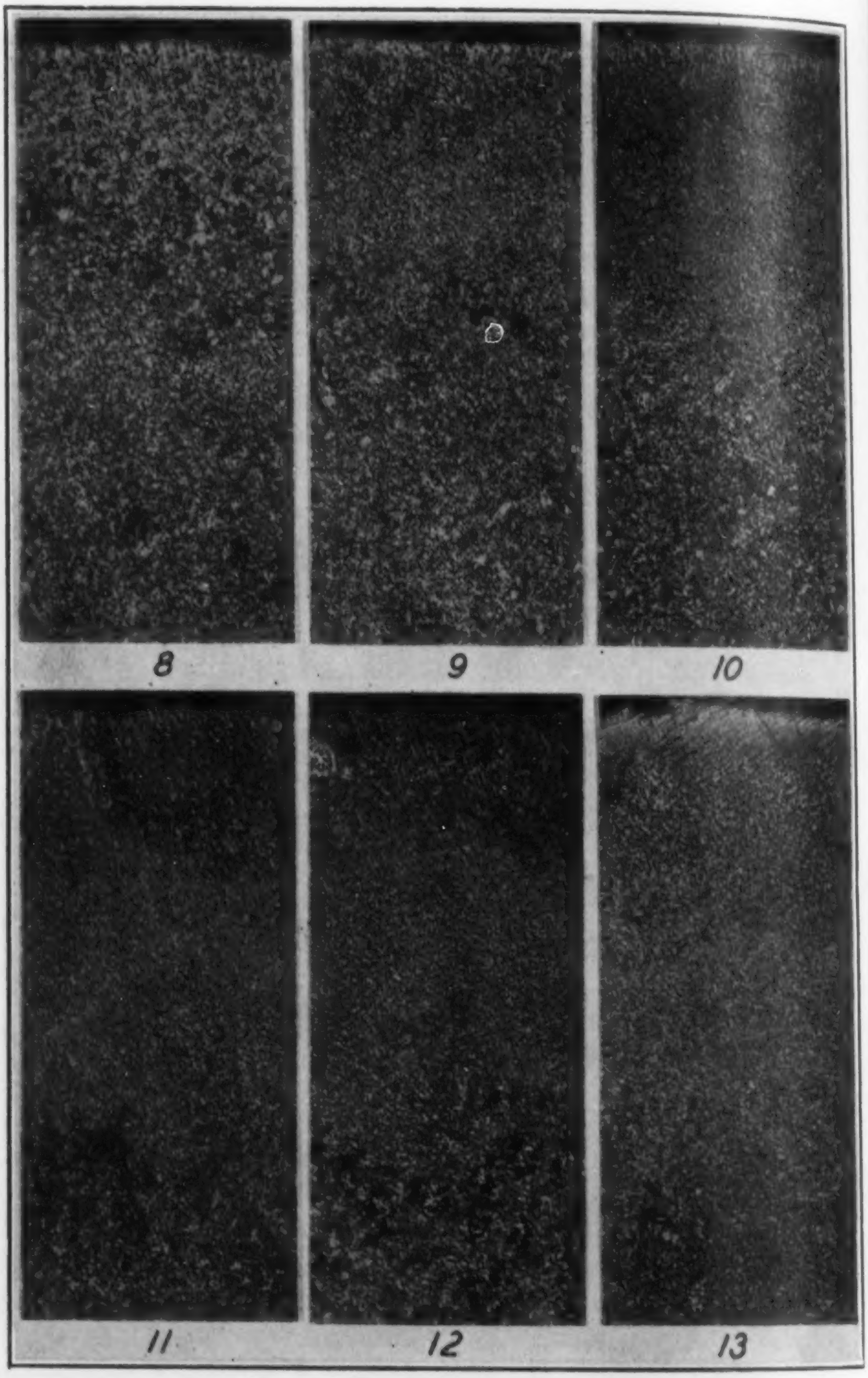
Fig. 1—Curves Showing the Carbon Penetration in Specimens, A1 to A6, B1 to B6, and C1 to C6. Series A1 to A6 is an S. A. E. 1120 Steel, Series B1 to B6 is an S. A. E. 2315 Steel, and Series B1 to B6 is an S. A. E. 3115 Steel. Analysis of Each Steel is Shown in Table I.

Each piece was carefully mounted in a fusible alloy in order to protect the edge as it was desired to show the depth of case resulting from each period of immersion. The series of photomicrographs Figs. 2 to 19 supplement the chemical analyses and offer an idea of the true depth of case. A carburized and oil-quenched piece would not indicate the same case depth to the unaided eye that the annealed piece does to the microscope, the latter being the greater depth and showing true penetration.

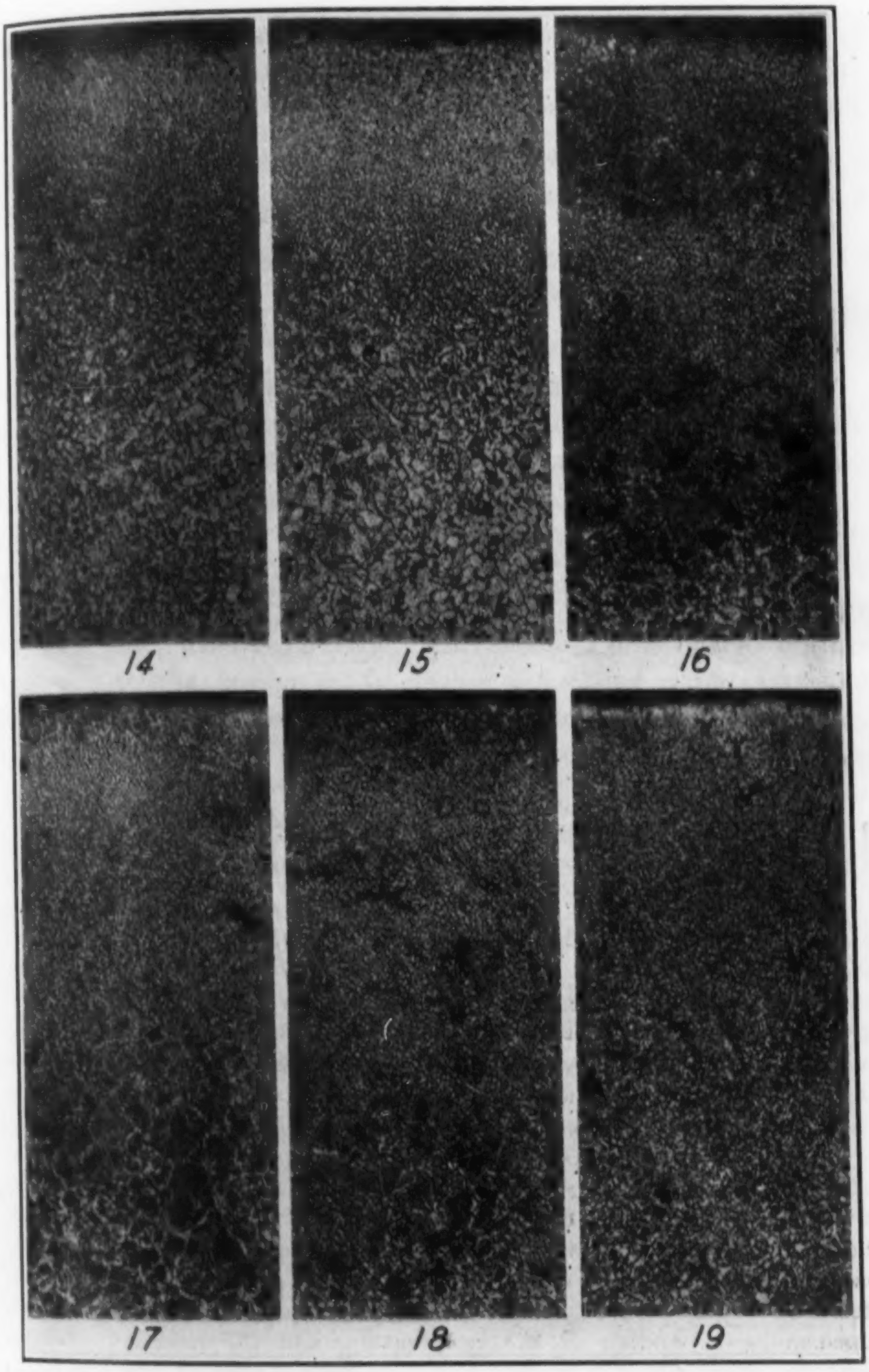
The steels did not absorb carbon from the bath at equal rates as shown by the analyses of the turnings, and the appearance of density of the carburized sections seems to be almost an inverse ratio of the carbon absorption rapidity. This is quite noticeable in the photomicrographs and follows in the same order as the densities of the original uncarburized stocks, viz., (1) nickel steel, (2) nickel-chromium steel and (3) plain carbon steel.



Figs. 2 to 7—Photomicrographs Showing Carbon Penetration in Specimens A1 to A6 After Treatment in a Cyanide Bath Heated at 1650 Degrees Fahr. Specimen A1 was Heated for 1 Hour; Specimen A2 for 2 Hours; Specimen A3 for 3 Hours; Specimen A4 for 4 Hours; Specimen A5 for 5 Hours; and Specimen A6 for 6 Hours. Steel Treated was S. A. E. 1120. Magnification 100 x.



Figs. 8 to 13—Photomicrographs Showing Carbon Penetration in Specimens B1 to B6 After Treatment in a Cyanide Bath Heated at 1650 Degrees Fahr. Specimen B1 was Heated for 1 Hour; Specimen B2 for 2 Hours; Specimen B3 for 3 Hours; Specimen B4 for 4 Hours; Specimen B5 for 5 Hours; and Specimen B6 for 6 Hours. Steel Treated was S. A. E. 2315. Magnification 100 x.



Figs. 14 to 19—Photomicrographs Showing Carbon Penetration in Specimens C1 to C6 After Treatment in a Cyanide Bath Heated at 1650 Degrees Fahr. Specimen C1 was Heated for 1 Hour; Specimen C2 for 2 Hours; Specimen C3 for 3 Hours; Specimen C4 for 4 Hours; Specimen C5 for 5 Hours; and Specimen C6 for 6 Hours. Steel Treated was S. A. E. 3115. Magnification 100 x.

After cyaniding and annealing as given above, hardness readings were obtained on the several pieces and these readings bear out the density statements above mentioned.

Rockwell "B" After Cyaniding and Annealing

Hours	A.	B.	C.
1	52	60	50
2	53	62	53
3	57	63	54
4	57	63	62
5	58	64	60
6	59	65	60

It is noticeable that the maximum hardness readings occur on those specimens which had attained maximum carbon concentration in the case, viz., after the 3-hour immersion.

While this report is of value in determining exactly the case depth obtainable by cyaniding the several classes of steel for different lengths of time under the given conditions, it is also very valuable from another viewpoint. The maximum carbon concentration in the case denotes that the steel so carburized does not have maximum hardening power which occurs at 0.85 per cent carbon in plain carbon steel and somewhat lower in the nickel steels.

DISCUSSION—ABNORMAL STEEL

(Continued from Page 435)

One is led to believe that the white substance surrounding cementite is identical with inclusions in the lower carbon regions of highly oxygenated steels and quite probably is an alloy of iron and carbon containing a considerable amount of oxygen. This assumption can account for crystallographic peculiarities of high oxygen steels. Austenite is seemingly capable to hold in solution comparatively large amounts of oxygen. On cooling two sets of transformations take place, normal allotropic changes in iron, and changes induced by the presence of oxygen. Precipitation of proeutectoid cementite taking place in the gamma range is not affected at all by the presence of oxygen. Cementitic mesh so formed is still filled by a homogeneous mixture of austenite and oxygen in whatever form it might be present. With the lowering of the temperature the uniformity of the mixture is destroyed and a constituent of higher oxygen content and lower fusibility begins to precipitate at the grain boundaries. Its solubility is presumably a function of the temperature, and the rejection continues until the lower critical is reached and the eutectoid alloy of iron and carbon with traces of oxygen is transformed into pearlite. Identical reasoning can be applied to hypoeutectoid steels substituting proeutectoid cementite by proeutectoid ferrite.

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—Part XIV[1]

BY H. B. KNOWLTON

Abstract

This article deals with the use of vanadium in various types of steel. The following points are brought out:—Vanadium acts as a cleaner and in addition it strengthens the ferrite and makes the cementite more stable. Carbon-vanadium steels are used in the manufacture of large forgings and castings, particularly those used in locomotive construction. A series of low and medium carbon chromium-vanadium steels are used in automotive construction. High carbon chromium-vanadium steels are used for tools and bearings. Vanadium is used with and without alloying elements in the manufacture of tool steels. The heat treatments, properties and uses of the different types of steel are described.

VANADIUM STEELS

WHILE vanadium ores are quite widely distributed in nature, pure vanadium metal has never been successfully produced on a commercial basis. It is, however, commercially practicable to produce alloys of vanadium and other metals. The alloy of iron and vanadium containing between 35 and 45 per cent of vanadium is known as ferrovanadium and is used in the production of vanadium alloy steels. While it has been used in this way for about thirty years, the principal use of vanadium in steel pro-

[1]This is the fourteenth installment of this series of articles by H. B. Knowlton. The several installments which have already appeared in TRANSACTIONS are as follows: March, June and October, 1925; January, April, May, June, August, October, December, 1926; March, May and July, 1927.

The author, H. B. Knowlton, member of the Fort Wayne Group of the Society, is metallurgist of the Fort Wayne Works, International Harvester Company, Fort Wayne, Ind.

duction has been confined to the last twenty years. Like that of some of the other alloy steels, the development of vanadium steels in this country has been closely associated with the development of the automobile.

When vanadium is added to steel it performs three functions. First, it acts as a cleaner of the melted steel in the process of manufacture, second, it strengthens the ferrite, and third, it combines with the carbon. It is said to be more effective than either manganese, silicon or aluminum in removing oxygen from steel. If it performed no other function it would be useful because a clean sound steel has greater strength and toughness than a steel which is less clean. The portion of the vanadium which combines with the oxygen, of course works up into the slag and is lost so far as the finished steel is concerned.

The amount of vanadium which is left in the finished steel is usually comparatively small. High speed tool steels may contain 1.0-2.5 per cent vanadium, but the ordinary low and medium carbon vanadium and chromium-vanadium steels is usually about 0.15-0.25 per cent. Even this small amount has a powerful influence upon the properties of the steel.

The microstructure of these steels is similar to the plain carbon steels as it is fundamentally composed of ferrite and cementite. Vanadium is somewhat similar to manganese because it enters into both the ferrite and the cementite. The ferrite containing vanadium is stronger, tougher and somewhat harder than ordinary ferrite. The cementite of vanadium steels is composed of iron carbide and vanadium carbide. If the vanadium content of the steel is raised to 5 per cent the cementite will be composed entirely of vanadium carbide. Commercial steels do not contain enough vanadium to bring this about. Cementite containing vanadium, probably does not dissolve into austenite quite as easily as pure iron carbide cementite. Also on slow cooling it does not tend to segregate in as large particles as the cementite in the plain carbon steels. Another valuable property of the vanadium steels is their ability to stand heating to higher temperatures without producing the large grain growth experienced in plain carbon and some other alloy steels. The microstructure of annealed vanadium steels does not contain the laminated or the parallel-plate form of pearlite found in plain carbon steels. The

structure presents rather a finer, more granular appearance. In general, the vanadium steels are frequently described as being of the fine-grained type. This is an advantage as the fine-grained structures are usually associated with toughness and resistance to shock.

Carbon-Vanadium Steels

Steels in which vanadium is the only alloying element, that is, the only element not found in the so-called plain carbon steels,

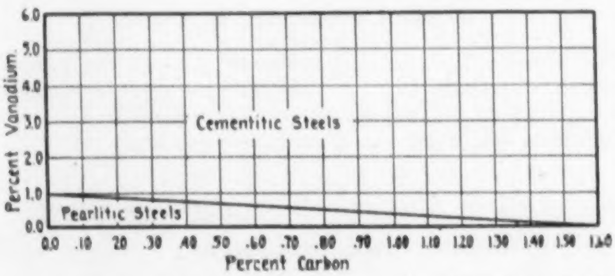


Fig. 1—Constitutional Diagram for Vanadium Steel (Guillet).

are sometimes called carbon-vanadium steels. If chromium, nickel or some other alloying element is added the steels produced are termed chromium-vanadium, nickel-vanadium, etc. The constitutional diagram (Fig. 1) shows the structure of steels containing different amounts of vanadium and carbon. These are the structures which are produced by slow cooling from temperatures above the upper critical point. This diagram is of interest principally from the scientific viewpoint as the only carbon-vanadium steels which are at present used commercially are those containing such small proportions of vanadium that they always fall in the pearlitic zone of the diagram.

Straight carbon-vanadium steels have found some popularity in the manufacture of large forgings such as used in locomotive construction, due to the physical properties which can be produced by annealing or air cooling. In the case of some of these forgings any heat treatment which involves quenching might be difficult to perform without producing quenching strains to a dangerous extent.

The A. S. S. T. Handbook gives the following data concerning the composition, heat treatment and physical properties of usual type of carbon-vanadium steel used for such locomotive

forgings as axles, crank pins, piston rods, connecting rods, etc.:—

Chemical Analysis

	Per Cent
Carbon	0.45-0.55
Manganese	0.70-0.95
Vanadium	0.15-0.25

Heat Treatment

Normalize: Heat to 1600-1650 degrees Fahr., cool in air.
Anneal: Reheat to 1000-1200 degrees Fahr.

Physical Properties Produced

Yield Point	60,000 pounds per square inch
Tensile Strength	90,000 pounds per square inch
Elongation in 2 Inches	20 per cent
Reduction of Area	40 per cent

The same steel is also recommended for parts which are to be treated by quenching and tempering. After quenching and tempering at 1100-1200 degrees Fahr., it is claimed that large forging will possess the following minimum physical properties:

Yield Point	100,000 pounds per square inch
Tensile Strength	130,000 pounds per square inch
Elongation in 2 Inches	20 per cent
Reduction in Area	50 per cent

The Carnegie Steel Co. states that it manufactures a carbon-vanadium steel for use as a flux in gas or electric welding. Here again the vanadium acts as a cleaner.

Carbon-vanadium steel castings containing 0.23-0.35 per cent carbon and a minimum of 0.15 per cent vanadium have found some popularity, particularly in locomotive construction. These castings should not be used in the as-cast condition, but should be annealed or normalized, or normalized followed by tempering at some temperature below the lower critical point. The accompanying data table showing the comparison between carbon steel and carbon-vanadium steel castings in the as cast, annealed and normalized conditions is taken from a paper by J. M. Lessells.[1] The writer has taken the liberty of rearranging and condensing the data.

It will be noted that the physical properties of the carbon-vanadium castings are in the main superior to those of the plain

[1]TRANSACTIONS, American Society for Steel Treating, Vol. V, No. 2, Feb., 1924.

Table I

Showing Comparison of Physical Properties of Carbon and Carbon-Vanadium Steel Castings

		Tensile Tests					Torsion Tests			Shock Tests		Endurance
Type of Steel*	Condition	Yield Point	Tensile Strength	Elongation, Per Cent	Red. of Area, Per Cent	Brinell Number	Yield Point	Ultimate Stress	Degrees, Twist	Repeated Blow, No. of Blows	Single Blow, Ft. Lbs.	Limit, Lbs. per Sq. In.
Carbon	Cast	33,500	76,200	26.0	34.0	141	34,600	60,500	460	676	5.8	32,000
Vanadium	Cast	37,300	80,800	23.6	29.6	156	23,000	56,900	697	760	6.6	39,000
Carbon	Annealed	41,200	79,800	26.8	39.5	143	25,800	59,500	840	980	13.0	36,000
Vanadium	Annealed	40,000	79,600	27.5	43.0	152	34,000	63,000	694	1000	15.0	42,000
Carbon	Normalized	45,800	84,900	27.6	45.6	163	28,470	62,600	1025	2000	18.0	36,000
Vanadium	Normalized	52,500	88,700	26.4	46.7	162	38,500	68,500	1045	2000	18.7	42,000

CHEMICAL ANALYSIS OF THE TWO TYPES*

Per Cent

	C	P	Mn	S	Si	V
Carbon	0.36	0.04	0.74	0.037	0.32	...
Vanadium	0.33	0.04	0.77	0.036	0.32	0.18

NOTE: The data in this table was taken from an article by J. M. Lessells, TRANSACTIONS, American Society for Steel Treating, Vol. 5, No. 2, February, 1924. The present arrangement is different from that appearing in the original article.

carbon steel castings. However, there seems to be little difference between the resistance to shock as shown by the impact values. The data also shows that in general better properties for the carbon-vanadium castings are produced by normalizing rather than by annealing. As an exception to this statement it may be noted that the endurance limit is the same for both normalized and annealed castings.

While discussing the physical properties of steel castings it may not be amiss to say that the test coupons may not represent the physical properties of all parts of the casting. The structure and consequently the properties produced depend upon the rate of cooling from the casting temperature and the rate of cooling from normalizing. Obviously both are dependent upon the size and shape of the section. Consequently if there is considerable difference between the size of the casting and the size of the test coupon there may be considerable difference between the physical properties. However, the same comparisons which are made between the different types of steel and the effects of different treatments as applied to the test coupons would probably hold true for the castings, although the actual figures might be different. Furthermore, one of the most important factors which govern the properties of castings is that of cleanness and soundness of the steel. It may be assumed that the test coupons selected for both the carbon and the carbon-vanadium steels were sound. However it may be argued that as vanadium is a cleaner there may be a greater probability of producing sound castings when vanadium is employed.

Chromium-Vanadium Steels

Vanadium is most commonly added to steel in conjunction with chromium. The usual composition is

	Per Cent
Chromium	0.80-1.10
Vanadium	0.15-0.20
Manganese	0.50-0.80
Sulphur	0.04 max.
Phosphorus	0.04 max.
Carbon	varying amounts depending upon the use

Guillet's diagrams for both the chromium and the vanadium steels have been given previously. It may be seen from these diagrams that neither the chromium nor the vanadium content

of the above described chromium-vanadium steels is high enough to place the steel out of the pearlitic zone of the diagrams. As might be expected, therefore, the ordinary chromium-vanadium steels are pearlitic after slow cooling from above the upper critical point. They are also subject to the same heat treatments as the plain carbon steels.

Vanadium tends to prevent the formation of laminated (or parallel-plate) pearlite. The structure of annealed chromium-vanadium steels is consequently much finer than that of the corresponding plain carbon steels. It may be described as more nearly sorbitic than pearlitic. The compounds of chromium, vanadium and carbon dissolve into austenite a little less readily than does plain iron carbide. Consequently slightly higher temperatures are customarily employed in heat treating the chromium-vanadium steel. This point may be illustrated by the following table which shows the temperatures recommended by the S. A. E. for normalizing and quenching some of the plain carbon and alloy steels containing about 0.30-0.45 per cent carbon.

S. A. E. Number	Type	Temperatures for Normalizing, Degrees Fahr.	Temperatures for Quenching, Degrees Fahr.
1035–1040	Plain Carbon	1650-1750	1525-1575
2340	3.5 per cent Nickel	1625-1725	1425-1475
3140	Low Chromium-Nickel	1625-1725	1475-1525
3335	High Chromium-Nickel	1600-1700	1425-1475
6140	Chromium-Vanadium	1650-1750	1550-1650

It should be noted that while higher temperatures are necessary for the proper heat treatment of chromium-vanadium steels, the grain size of these steels is not so easily coarsened by heating to the higher temperatures.

Like most of the alloy steels, the chromium-vanadium steels are not often used except in the heat treated condition. The full value of the alloy is only obtained by heat treating. When the finished parts are machined from bar stock no normalizing treatment should be necessary. Drop forgings, on the other hand, should be normalized before proceeding with further treatments.

The heat treatments, properties and uses of the chromium-vanadium steels of varying carbon contents may be best discussed by dividing them into several classes following the S. A. E. classification.

6120—Case Hardening Chromium-Vanadium Steel

This is a chromium-vanadium steel containing 0.15-0.25 per cent carbon. It is used primarily for case hardening but may be used for some structural parts after suitable heat treatment. The low carbon chromium-vanadium steels are inherently fine-grained. When the McQuaid-Ehn test (which consists in examining carburized slowly cooled steel under the microscope) is applied to chromium-vanadium steel, it is found that the grain size is much smaller than that of the so-called "normal" structure of plain carbon and some other alloy steels. Judging by the grain size, the mistake might be made of classifying all chromium-vanadium steel as "abnormal". However, a chromium-vanadium case hardening steel may be "normal" in the best sense of the word and may behave perfectly normally during case hardening, which the truly "abnormal" do not do.

The carburizing temperatures usually recommended for 6120 steel are 1650-1700 degrees Fahr. If a double quenching treatment is given, the first quench should be from 1600-1650 degrees Fahr. and the quenching medium should be oil. The final quench should be from 1425-1475 degrees Fahr. As usual with all case hardening, the quenching treatments should be followed by tempering from 250-500 degrees Fahr., to relieve the strains set up by quenching.

One of the claims made for carburizing chromium-vanadium steel is that it absorbs carbon more rapidly than do some of the other carburizing steels, also that it hardens uniformly.

S. A. E. 6125-6130 Steels

These are chromium-vanadium steels containing 0.25-0.35 per cent carbon. They are used for parts which require considerable strength and toughness. It is not possible to obtain quite as high values for tensile strength and yield point with these steels as with the similar steels with slightly higher carbon content. The heat treatment recommended for these steels is as follows:

Normalize	1650-1750 degrees Fahr.
Heat	1575-1675 degrees Fahr.
Quench	
Temper as required	

As these steels are fairly low in carbon content, they may be quenched in water. The physical properties produced by heat treating S. A. E. 6130 steel are shown by the graph, Fig. 2.

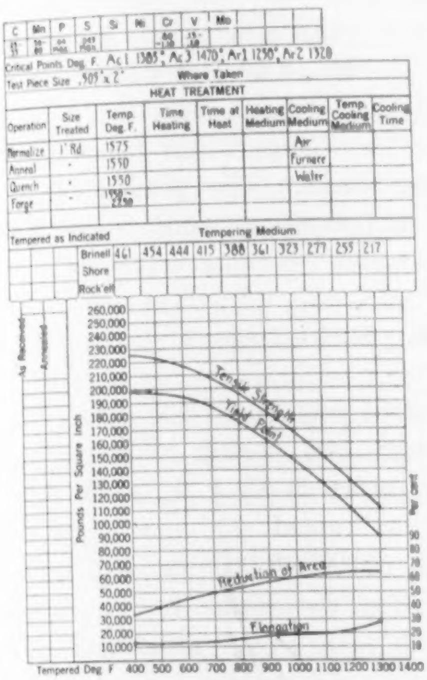


Fig. 2—Curves Showing Physical Properties of S. A. E. 6130 Steel Heat Treated as Indicated Above.

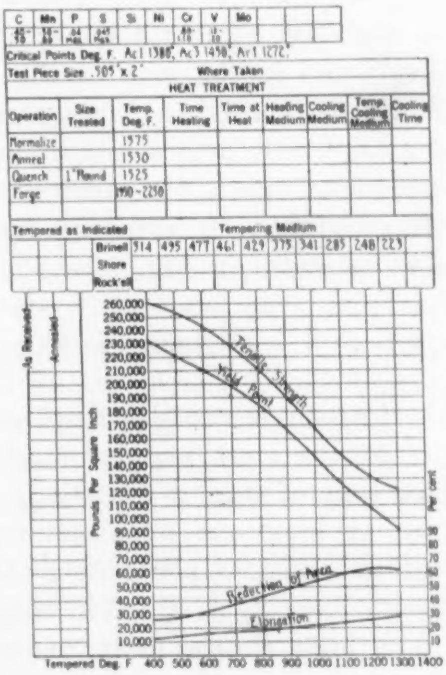


Fig. 3—Curves Showing Physical Properties of S. A. E. 6145 Steel Heat Treated as Indicated Above.

S. A. E. 6135-6140 STEELS

These steels are similar to the ones previously described except that the carbon content is a little higher, the average carbon being 0.35 and 0.40 per cent as indicated by the last two figures of the specification numbers. These steels are generally quenched in oil and tempered to meet the requirements. The quenching temperature recommended is about 25 degrees Fahr. lower than for the S. A. E. 6130-6135 steels. On account of the carbon content these steels may not machine quite as freely as those lower in carbon. When parts are to be machined from these steels before giving the final heat treatments, the S. A. E. specifications recommend that the steel be normalized followed by tempering at 1250-1350 degrees Fahr. This produces a more machinable structure.

S. A. E. 6145-6150 Steels

These are primarily gear steels. With the higher carbon content it is possible to produce good hardness and resistance to wear by oil quenching and tempering. At the same time due to the alloy content these steels are quite strong and tough. As mentioned in the case of the S. A. E. 6135 and 6140 steels, it is well to normalize forgings and then reheat them to 1250-1350 degrees Fahr. before machining. The temperature recommended for quenching is 1525-1625 degrees Fahr. The physical properties produced by applying such a treatment to S. A. E. 6145 steel is shown in Fig. 3.

Chromium-Vanadium Spring Steel

Chromium-vanadium spring steel has been, for some years, one of the most popular steels with the spring manufacturers. This type of steel is essentially the same as S. A. E. 6145. However, at least one manufacturer has raised the manganese content to 0.85-1.00 per cent instead of 0.50-0.80 per cent usually specified for S. A. E. 6145 steel. The requirements for a spring are a high elastic limit combined with great toughness. The chromium, vanadium, and manganese contents all help to raise the elastic limit without proportional sacrifice of toughness. It will be noted that the carbon content is roughly about one-half of that of the ordinary plain carbon spring steel. This also helps to maintain the toughness of the steel. The heat treatments consist in normalizing followed by quenching in oil from 1550 degrees Fahr. and tempering at some temperature between 700 and 1100 degrees Fahr.

S. A. E. 6195 Steel

This steel has a carbon content of 0.90-1.05 per cent, while the manganese is specified as 0.20-0.45 per cent and the sulphur and phosphorus below 0.03 per cent. Consequently this steel belongs in the tool steel class. It is used somewhat in bearing manufacture and for certain machine tool parts. When parts are machined for annealed bar stock the heat treatment required consists in heating to about 1500-1550 degrees Fahr., quenching

in oil and tempering as required. If it is forged it must be annealed carefully before machining. The following treatment for producing machinability is given by the S. A. E.

Heat to 1650-1750 degrees Fahr.
Cool to 1000 degrees Fahr. (black heat) by opening the furnace door.
Reheat to 1300 to 1350 degrees Fahr. and hold at temperature for at least 36 hours or until desired machinability is obtained, then cool slowly in the furnace.

Chromium-Vanadium Tool Steel

There is a whole series of chromium-vanadium tool steels which are similar to the plain carbon tool steels excepting for the addition of the two alloying elements. The carbon content varies from 0.50-1.00 per cent. The heat treatments and uses are in the main similar to those of the plain carbon tool steels. Due to the alloy content these steels are stronger and tougher than the ordinary carbon tool steels. Camp and Francis describe two main types of chromium-vanadium tool steels having the following chemical composition, and uses.

Chemical Composition of the Chief Types of Chromium-Vanadium Tool Steels[1]

	Medium Chromium	High Chromium
Carbon	0.50-0.90 per cent, according to temper	0.95-1.10 per cent
Manganese	0.15-0.35 per cent	0.10-0.30 per cent
Silicon	0.15-0.25 per cent	0.20-0.30 per cent
Sulphur	0.04 per cent maximum	0.04 per cent maximum
Phosphorus	0.04 per cent maximum	0.04 per cent maximum
Chromium	0.70-0.90 per cent	1.30-1.60 per cent
Vanadium	0.15-0.25 per cent	0.15-0.25 per cent

[1]From Camp and Francis:—Making, Shaping and Treating of Steel.

The uses of these steels correspond with those of the plain carbon tool steels of slightly higher carbon contents. For example, a plain carbon steel with 1.10-1.20 per cent of carbon is usually recommended for drill reamers and edge tools in general, while a chromium-vanadium tool steel containing 0.80 per cent carbon, 0.80 per cent chromium and 0.15-0.25 per cent vanadium is recommended for the same uses.

Vanadium in Alloy Tool Steels

Vanadium appears as a secondary alloying element in so many of the alloy tool steels that a detailed discussion concern-

ing all of the uses of vanadium in alloy tool steels will not be attempted. Most, if not all, of the high speed tool steels contain more or less vanadium. The content of this element varies from about 0.50 per cent to about 2.0 per cent. The most common composition is 1.0 per cent or more. A small portion of the vanadium acts as a scavenger cleaning the steel during the process of manufacture. The rest of the vanadium is said to improve the high speed cutting qualities of the tools.

Some of the oil hardening or non-deforming tool steels contain 0.15-0.25 per cent vanadium in combination with manganese, tungsten, or chromium. In these steels the action of the vanadium is probably the same as in the case of the structural vanadium and chromium-vanadium steels already described. Small amounts of vanadium are also employed in hot work, fast finishing and other alloy tool steels.

Carbon-Vanadium Tool Steels

In nearly all of the cases above mentioned the vanadium is used in conjunction with some other alloying element. It should be mentioned, however, that vanadium added to plain carbon tool steel is the only alloying element thus forming a series of carbon-vanadium tool steels. These steels are given the same heat treatments as the corresponding plain carbon tool steels and are used for similar purposes.

Vanadium and Other Alloying Elements

This article has been confined principally to the discussion of steels containing either vanadium alone or chromium and vanadium as the alloying elements. It should be mentioned in passing that vanadium has been used in combinations with other elements. Nickel-vanadium and chromium-nickel-vanadium combinations have both been tried.

Conclusion

In this article as in the previous articles of this series it has been attempted to set forth briefly the advantages claimed for the particular steel under discussion. It must be borne in mind that this is one of several types of alloy steels. Each has its

friends and its enemies. In this series of articles the writer has attempted to describe each steel fairly and avoid expressing any personal prejudice.

It may be said, then, that the claims for the addition of vanadium to steel are that the vanadium acts as a cleaner making the steel more sound. Furthermore, it alloys with the iron, forming a stronger ferrite and combines with the carbon forming a more stable form of cementite. With proper heat treatment it is possible to produce some very good physical properties with chromium-vanadium steel. One of the principal characteristics of vanadium and chromium-vanadium steels is that they are dense and fine-grained.

SCIENTIFIC RESEARCH AND ITS APPLICATION TO INDUSTRY

(Continued from Page 469)

market situation is meant both the economical purchase of raw material and the exploiting and selling of the finished product.

The first essential to success is a clear understanding of what such changes as are indicated involve. The second essential is the selection of a balanced personnel of well equipped mentality to carry it through. The third essential is the availability of sufficient funds and the willingness to spend such funds as to reasonably guarantee success.

Such success can be attained on a large scale only after much thought and work, and requires an organization with mental, physical and financial equipment directed in such a manner that it resembles the organization and placement of a modern army in a successful campaign.

When such conditions exist the results of successful research and its application to industry become a public benefit and those engaged in it are public benefactors.

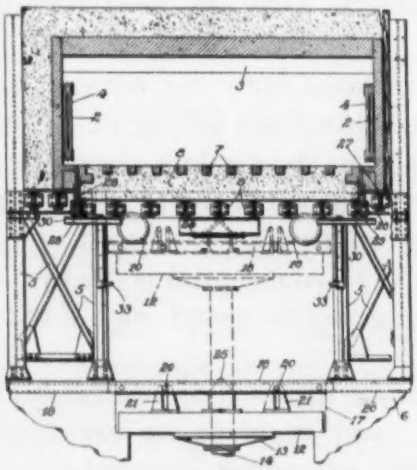
By such work whole nations are enriched, and when often repeated has resulted in bringing whole peoples to the front rank of civilization and comfort. The beginning of it all can be summed up in three words; inquisitiveness, initiative and enterprise.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,636,041, Electric Furnace, Harry O. Breaker, of Winthrop, Massachusetts.

This patent describes an electric furnace which is designed to prevent the loss of heat during the charging of the same. The furnace comprises side walls 2 supporting the resistors 4 and the top 3 permanently built together. The bottom comprises a car 8 mounted on the wheels 10 and having a refractory bed on which the articles to be treated may be placed. A hydraulic piston 14 is used to raise and lower the



truck 8 into and out of the furnace. In use two trucks 8 were preferably used, one being removed from the furnace chamber and run off on the tracks 20 when the piston 14 is lowered and the other charged truck being run on the platform from the tracks 19 and elevated into the furnace. Seals 28 and 29 assist in preventing the escape of the heat when the truck is in position, closing the bottom of the furnace. The location of the furnace with the charging opening in the bottom thereof prevents the substantial loss of heat in the operation of the same.

1,630,162, Furnace, James Boucek and James Halick, Cleveland, Ohio, Assignors of one-third to Joseph Trefney, Cleveland.

This furnace comprises an oven having its sides and top and back spaced from the interior walls of the furnace, with a combustion chamber below the oven and having its front end in communication with the space between the oven and the interior walls of the furnace. The products of combustion are made to pass in a zigzag path to the rear of

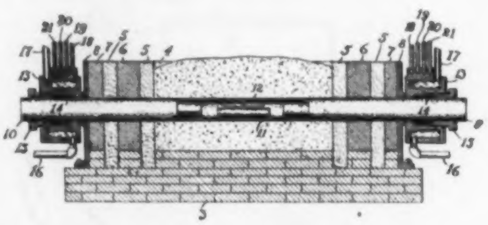
the oven. Fuel is introduced into a combustion space at the rear of the combustion chamber.

1,629,968, **Metallurgical Furnace Feeding Mechanism, Adelbert Harry Richards, Salt Lake City, Utah, Assignor to American Smelting and Refining Co., New York.**

This furnace feeding device has a feed chute with a number of feed gates for feeding charges to the furnace. A drive shaft is provided having a wheel for each gate, each wheel having an operating sector and a non-operating sector and a separate device for opening and closing each gate, each of these devices being operated by the operating sector of the respective wheel.

1,637,052, **Process of Producing Metallic Carbon, Conway Robinson, of Baltimore, Maryland, Assignor to Westinghouse Electric and Manufacturing Company, of New York, a Corporation of Pennsylvania.**

This patent describes a process of making pure metallic carbon which is malleable, ductile and generally workable having a high melting point and lower vapor pressure and differs from the ordinary forms of amor-



phous carbon by being in a higher state of purity and uncontaminated by other substances. The process used comprises placing anthracite coal in small pieces and surrounded by cellulose, of which raw cotton is an example, into a graphite resistor tube 11 provided with a suitable door 12. Graphite electrodes 9 and 10 having reduced ends adapted to fit into the tube 11 are passed into each end of the furnace through the side walls consisting of alternating layers of refractory material 5 and insulating material 6. The tube 11 is packed in granular graphite extending substantially to the top of the furnace and a current is sent into the tube through the electrodes 10 to bring the tube to a temperature in the region of 3500 degrees Cent. which temperature is maintained for a suitable length of time to break down the coal or other carbon compound and eliminate all impurities, leaving ultimately elemental metallic carbon in a pure and free state.

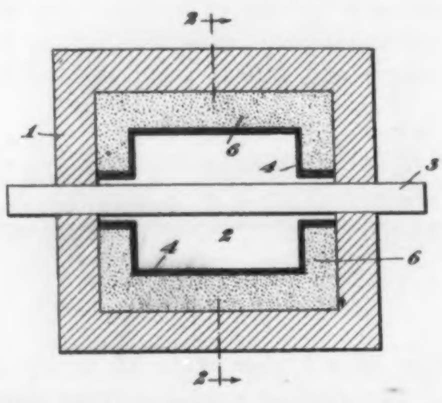
1,632,704, **Casting Having Chromium Alloy Surface, Charles B. Jacobs, Wilmington, Del., Assignor, by mesne assignments, to Electric Metallurgical Co.**

This method of making a ferrous metal casting having a chromium alloy surface layer that is strongly resistant to oxidation, consists of

coating a surface in the mold in which the casting is to be formed to a depth of from about one-eighth to one-quarter of an inch with a mixture composed of metallic particles of chromium and a binder hardening the resulting coating, and then introducing into the mold molten ferrous metal at a pouring temperature of from about 2650 to 2900 degrees Fahr., the size and disposition of the metallic particles in the coating being such as to permit ready penetration therebetween by the molten metal and solution of the particles by the molten metal.

1,637,486, Electric Furnace, James Kelleher, of Chippewa, Ontario, Canada, Assignor to Harper Electric Furnace Corporation, a Corporation of New York.

This patent describes an electric furnace employing carbonaceous resistors 3 particularly designed to prevent deterioration of the resistors due to the action of silicon vapors which are produced by the decomposition of the silicates in the walls of the furnace. 1 indicates the usual



firebrick or other refractory walls, 2 the furnace chamber and 3 the resistors. The furnace chamber is lined with slabs 4 of graphite or other carbonaceous material and the space between the lining 4 and the walls of the furnace is packed with amorphous silicon carbide. By varying the thickness of the packing 6 between the plates 4 and the walls 1 the danger of silicon vapors entering into the resistor chamber 2 from the silicious refractories in the walls 1 is practically eliminated.

1,636,657, Making Malleable Iron Castings, Harry A. Schwartz, of Cleveland Heights, Ohio, Assignor, by Mesne Assignments, to National Malleable and Steel Castings Company, of Cleveland, a Corporation of Ohio.

This patent describes a method of making malleable castings in which the detrimental effect of too much silicon, which often causes the precipitation of carbon in flaky form as the castings are cooling in the mold, is overcome by the use of a graphitization accelerator, such as uranium, nickel, titanium or aluminum. In practicing the invention, iron containing no substantial percentage of silicon and approximately 0.10

to 0.15 per cent of titanium or aluminum may be cast without precipitating the carbon, and when annealed graphitizes as completely and more satisfactorily than normal malleable iron containing 0.60 to 0.75 per cent of silicon with no titanium or aluminum. The practice of the invention is particularly beneficial in the case of castings of heavy sections where slow cooling tends to promote precipitation of carbon in the mold.

1,636,763, **Metallic Composition, Henrik Boving, of New York, N. Y., Assignor to Western Electric Company, Incorporated, of New York, a Corporation of New York.**

This patent describes a method of making an alloy between metals of a low volatilization point and metals having a high melting point. The difficulty previously experienced in connection with alloys of nickel and barium is that the addition of the barium to the molten nickel is accompanied with a high loss of barium due to sudden volatilization when heated to the temperature of the molten nickel. Under the present invention the barium and nickel are weighed and reduced to a finely divided state and thoroughly mixed under conditions which will prevent surface oxidation. The homogeneous composition is then placed in a mold or die of any desired shape and the barium is brought to a molten state without allowing the metal to flow freely, either by increasing the temperature or exerting a sufficiently high pressure upon the mixed material. The use of pressure to bring the barium to a molten state is preferable because it is easier to control and results in no loss due to volatilization. The use of temperature must be carefully controlled to prevent the barium from being heated to a highly molten state and volatilized.

1,630,587, **Kiln and Other Heat Treatment Furnace, Charles William Speirs, Battersea, London, England, Assignor to Morgan Crucible Company, Ltd., England.**

In this tunnel kiln, the firing zone is formed by an electric resistor fixed vertically in the center of the tunnel so that the heat is radiated equally from both sides on to two streams of articles passing either in the same or opposite directions.

1,630,784, **Annealing or Heating Furnace, James R. Coe, Waterbury, Conn., Assignor to The American Brass Company, Waterbury, Conn.**

A heating chamber in this furnace contains a carrier mounted to revolve in a vertical plane and has means at its periphery for carrying holders for the material to be heated, and mechanical means for inserting the holders in and removing them from the carrier.

1,628,964, **Drill-Heating Furnace, Harold K. Fox, Fresno, Calif.**

This furnace is provided with a slot in the side of the furnace adapted for the insertion of tools to be treated for passage along the slot, this slot having enlargements at spaced points for the passage of the heads of the tools and a restricted portion to prevent their withdrawal, connecting the enlargements.

THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,200 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

ALLOY STEELS

CEMENTATION. New Research on the Cementation of Ferrous Alloys by Chromium and Tungsten (Nouvelles recherches sur la cémentation des alliages ferreux par le chrome et par le tungstene), J. Laissus. Revue de Métallurgie, vol. 24, no. 6, June 1927, pp. 345-352, 3 figs. Study of surface hardness of cemented metal, resistance to oxidizing action at high temperature, polishing facility, resistance to corrosion by water and to corrosion by certain acid solutions.

COPPER, CONTAINING. The Resistance to Corrosion of Steel Containing Copper (L'acier au cuivre sa resistance a la corrosion), M. Grison and L. LePage. Revue de Metallurgie, vol. 24, no. 6, June 1927, pp. 331-336, 1 fig. Results of mechanical tests.

ALLOYS

ACID-RESISTING. Acid-Resisting Alloys with Nickel Basis (Säurefeste Legierungen mit Nickel als Basis), W. Rohn. Zeit. für Metallkunde, vol. 18, no. 12, Dec. 1926, pp. 387-396, 11 figs.; and translation in Chem. & Met. Eng., vol. 34, no. 7, July 1927, pp. 417-420. Several years of experimental work in research laboratories of Heraus Vacuumschmelze, who employ electric vacuum melting of alloys on large industrial scale, has resulted in accumulation of considerable information regarding corrosion-resisting properties of these metals and alloys; alloys investigated can not be produced in workable and ductile form except by vacuum melting process; presents table of loss in weight in grams per square decimeter for vacuum-melted metals and alloys when exposed to various acids.

CORROSION-RESISTANT. Selection of Corrosion Resistant Alloys, W. M. Mitchell. Forging-Stamping-Heat Treating, vol. 13, no. 6, June 1927, pp. 204-207. Discusses mechanism of corrosion together with factors involved and reviews modern practice in combating destruction of metals.

TRANSFORMATIONS IN. Some Transformations in Alloys. Metallurgist (Supp. to Engineer), June 24, 1926, pp. 90-91, 2 figs. Review of paper by G. Tammann and O. Heusler, published in Zeit. für anorganische u. allgemeine Chemie, 1926, pp. 168 and 349; theory advanced by authors appears to explain some of phenomena observed.

SMELTING SECONDARY. Smelting Secondary Aluminum and Aluminum Alloys, R. J. Anderson. Metal Industry, (N. Y.), vol. 25, no. 7, July 1927, pp. 281-283, 4 figs. Preparation of aluminum scraps for smelting.

ALUMINUM ALLOYS

ALUMINUM-BERYLLIUM. The Mechanical Properties of the Binary Aluminum-Beryllium Alloys, W. Kroll. Metal Industry, (Lond.) vol. 30, no. 26, July 1, 1927, pp. 645-646. Summarizes some of most important recent results; they appear to indicate that influence of beryllium is closely akin to that of silicon, and not as effective as later, when added to aluminum; utilization for aircraft is, therefore, doubtful proposition.

CEMENTATION. Cementation of Aluminum, Magnesium and Light and Ultra-Light Alloys (Sur les recouvrements de l'aluminium, du magnésium, et des alliages legers et ultra-legers), J. Cournot, J. Bary and E. Perot. Académie des Sciences—Comptes Rendus, vol. 184, no. 20, May 16, 1927, pp. 1172-1174. Penetration of aluminum by copper during cementation process is not influenced by current density below 0.7 amperes; above this non-adherent deposit is obtained; rapid cementation is also produced in bath containing equal parts of sodium nitrite and potassium nitrate at low temperatures; satisfactory cementation is not produced on pure aluminum with ferrochromes, nor on magnesium and its copper alloys, chiefly on account of difficulty of producing efficient cleaning; rapid and complete cementation of duralumin by ferrochromes of low carbon content was obtained after 1 hr. at 580 deg.

CORROSION. Corrosion Phenomena in Aluminum Alloys (Korrosionserscheinungen an Aluminiumlegierungen), E. Maass and W. Wiederholt. Korrosion u. Metallschutz, vol. 2, no. 10, Oct. 1926, pp. 234-238, 5 figs. Discusses behavior of alloys in acids from tests made at Reichsanstalt; concludes that no alloys are more acid resistant than pure aluminum.

HARDNESS AND TENSILE STRENGTH. Relation between Brinell Hardness and Tensile Strength of Pure Aluminum and High-Grade Aluminum Alloys (Ueber den Zusammenhang zwischen Brinellhärte and Zugfestigkeit bei Reinaluminium und vergutbaren Aluminiumlegierungen), H. Bohner. Zeit. für Metallkunde, vol. 19, no. 5, May 1927, pp. 211-214, 4 figs. For pure aluminum as well as for aluminum alloys it is possible with aid of simple formulas to calculate strength from Brinell hardness or, vice versa, to calculate Brinell hardness from tensile strength; general problems for determining of Brinell hardness of thin specimens.

HIGH-STRENGTH. Light Alloys [Quelques précisions à propos du K. A. (Koltchougaluminum)], Aérotechnique, vol. 9, no. 96, May 1927, p. 145. Aluminum high-strength light-weight alloy manufactured in Russia; composition is as follows: copper 4.5 per cent, maganese 0.6 per cent, nickel 0.3 per cent, magnesium 0.5 per cent, aluminum 93.5 per cent; metal is used in annealed or drawn-back state for pressed work, normally quenched for sheared work and riveting; cold worked for shearing, riveting and high strength purposes; highest and best temperature from which to quench is 520 deg. cent. See brief translated abstract in Automotive Abstracts, vol. 5, no. 7, July 20, 1927, p. 218.

INDUSTRIAL USES. Industrial Utilization of Aluminum Alloys (A propos de l'utilisation industrielle des alliages d'aluminium), H. Pommerenke and P. Herman. Revue de Métallurgie, vol. 24, no. 6, June 1927, pp. 297-306, 6 figs. Discusses following questions: What is best light alloy to meet requirements of many industries, particularly automobile and motorcycle industry; what heat treatment is most desirable for this alloy from point of view of efficiency and cost.

INTERMEDIATE HARDENERS. Intermediate Aluminum Alloys (Hardeners) For Use in Preparing Light Aluminum Alloys, R. J. Anderson, Am. Metal Market, vol. 34, no. 137, July 16, 1927, pp. 4-7, 25 figs. Intermediate aluminum alloys are used extensively in practice as vehicles for making fixed additions of metals to aluminum in preparation of light alloys; in foundry parlance, intermediate alloys are usually referred to as "hardeners" or "rich alloys;" list of intermediate alloys and properties; preparation; microstructures.

SILVER-ALUMINUM. Heat-Treated Silver-Aluminum Alloys. Metallurgist (Supp. to Engineer), June 24, 1927, pp. 83-85, 2 figs. Refers to article by Kroll, published in Metall. u. Erz, vol. 23, 1926, p. 555, showing that aluminum-silver contains alloys that can be improved by heat treatment; alloys in question are those of low silver content, and they have been shown to undergo marked age hardening; mechanism depends on fact that by reason of solubility of alloyed metal, in this case silver, in solid aluminum, and fact that its solubility increases appreciably with rise of temperature, super-saturated solid solution of silver in aluminum can be obtained by quenching.

TENSILE TESTS. Grooved and Uniform Expansion with Tensile Tests (Ueber Einschnür und Gleichmassdehnung beim Zugversuch), O. Tiedemann. Zeit. für Metallkunde, vol. 19, no. 6, June 1927, pp. 249-252, 1 fig. Numerical relations between total, grooved and uniform expansion; effect of aging on both kinds of expansion in case of certain aluminum-zinc alloys.

ALUMINUM BRONZE

TRANSFORMATIONS IN. Transformations Undergone by Aluminum Bronzes (Transformations subies par les bronzes d'aluminium), J. Bouldoires and L. Guillet. Académie des Sciences—Comptes Rendus, vol. 184, no. 18, May 2, 1927, pp. 1071-1073. In air as medium, cooling curve showed change of direction at 500 deg., but when cooling was accelerated by compressed air, marked anomaly with liberation of heat was obtained at 125 to 150 deg.; this was due to lowering of temperature of transformation recorded for heating curve; after tempering in air structure was martensitic.

TREATMENT. Light Alloys, L. Aitchison. Automobile Engr., vol. 17, no. 229, June 1927, pp. 220-222. Deals with five groups of metals arranged according to essential characteristics of different types of alloys, including alloys of aluminum which are useful only in cast condition; alloys which are cast, but which before casting are modified or subject to certain treatment while in molten state; alloys which can be cast but which are susceptible to modification after casting; among these are included metals which may usefully be submitted to some treatment to improve their physical properties when in solid state; alloys which can usefully be worked, and can be used in worked condition, forging or other work being carried out either in hot or cold state.

AUTOGENOUS WELDING

ALUMINUM ALLOYS. Autogenous Welding of Aluminum Alloys Employed in Automobile Construction (Soudure Autogène des pièces en Alliages d'aluminium employée en Construction Automobile), J. Bert. Revue de Métallurgie, vol. 24, no. 6, June 1927, pp. 337-344, 3 figs. Results of mechanical tests; influence of preparation of pieces; influence of temperature and of composition of metal; influence of heat treatment and cold working.

BEARING METALS

ANTI-FRICTION. Notes on the Composition of Anti-Friction Metals. Mech. World, vol. 82, no. 2114, July 8, 1927, p. 23. Ternary alloys have proved most successful as bearing metals; tin-antimony-copper, tin-lead-copper, and tin-antimony-lead are most popular; mentions principal metals present in bearing alloys, with their effects.

THERMIT. Bearing Metals, Particularly "Thermit" (Etwas über Lagermetalle, speziell "Thermit"), Maschinen-Konstrukteur, vol. 60, no. 8, Apr. 30, 1927, pp. 192-194, 7 figs. Comparative metallographic study of "Thermit" and other bearing metals, includ-

ing hardness tests, behavior under operating conditions, etc.; demonstrates physical and economic superiority of "Thermit."

BLAST FURNACES

FLUE DUST AND CONTROL. Blast Furnace Flue Dust and Blast Furnace Control, E. Kieft. Iron & Steel Engr., vol. 4, no. 7, July 1927, pp. 345-348, 3 figs. Makes calculations pertaining to cause of flue-dust production; importance of necessary height between stock level and center of downcomers is calculated with consideration of prevailing conditions encountered in practical operation.

GAS WASHERS. New Gas Washer for Ohio Furnace. Iron Age, Vol. 120, no. 4, July 28, 1927, pp. 198-200, 6 figs. Large stack recently completed by Wheeling Steel Corporation at Steubenville; electric bell hoist used; gas washer consists of cylindrical steel shell 72 ft. high and 18 ft. in diameter, divided into six compartments or stages.

LOSSES IN AIR DUCTS. Calculation of Losses in Air Ducts in Blast Furnaces (Calcul des pertes de charge dans les conduites à vent des hauts-fourneaux), M. Derclaye. Revue de Métallurgie, vol. 24, no. 5 and 6, May and June 1927, pp. 237-254 and 317-330, 14 figs. Determination in loss in rectangular element in circular duct; influence of operating conditions; applications of different types of furnaces.

OXIDATION PROCESSES. Influence of Oxidation on Blast Furnace Process (Einfluss an Oxydationsvorgängen auf den Hodhofenprozess), H. Bansen. Stahl u. Eisen, vol. 47, no. 24, June 16, 1927, pp. 1005-1010, 1 fig. Critical discussion of work by F. Wüst and reply by Wüst.

BOILER PLATE

STRENGTH PROPERTIES. Strength Properties of Boiler Plates at Temperatures of 20 to 600 deg. Cent. (Festigkeitseigenschaften von Kesselblechen bei Temperaturen von 20 bis 600°), G. Urbanexyk. Stalh u. Eisen, vol. 47, no. 27, July 7, 1927, pp. 1128-1135, 11 figs. Results of strength tests for four types of plates conforming to new specifications for land-type boilers.

BOILERS

FUSION WELDING. Fusion Welding on Boilers and Pressure Vessels, F. W. Miller. Power, vol. 66, no. 3, July 19, 1927, p. 113. There are now being built tanks 7 ft. in diameter, 35 ft. long, of $\frac{11}{16}$-in. material for 200 lb. working pressure, based on design fiber stress of 9000 lb. per sq. in.; seams are all double V-welded with welding wire whose tensile strength as deposited in weld, is 65,000 lb. per sq. in., which has elongation on average of 15 per cent in 2 inches.

BRASS FOUNDRIES

PRACTICE. The Fundamentals of Brass Foundry Practice, R. R. Clarke. Metal Industry (N. Y.), vol. 25, nos. 1, 2, 3, 4, and 5, Jan., Feb., Mar., Apr. and May, 1927, pp. 6, 63-64, 105-106, 146-148 and 194-195, 2 figs. Description of basic laws which control melting and casting of metals and their application to practical foundry operations. Jan.: Pouring temperature. Feb.: Gating. Mar.: Radiation and concretion. Apr.: Effect of gravity and of laws of motion. May: Pressure in different parts of mold; effect of delivering metal to mold at different angles.

BRONZES

CASTING STATUARY. Creating Life in the Bronze, L. S. Monroe. Brass World, vol. 23, no. 7, July 1927, pp. 223-224, 6 figs. Description of processes of casting statues for many objects of art; how likenesses are finished for final use; Gloucester fisherman as an example.

PHONO. Characteristics of Phono Bronzes. Am. Mach., vol. 67, no. 5, Aug. 4, 1927, p. 201. Phono bronzes are alloys, high in copper, containing small amounts of tin, approximately 1¼ per cent, and fluxed with silicon; their outstanding properties are in their ability to be hot-worked, and to be strengthened by cold work to high degree without losing their toughness or becoming brittle. Reference-book sheet.

TIN, INFLUENCE OF. Tin in Copper (Einfluss des Zinns auf die mechanischen Eigenschaften des Kupfers), W. Stahl. Chemiker-Zeitung, vol. 51, no. 44, June 4, 1927, p. 427. Fact that high-tin bronzes have higher density than would be expected from component densities is due to elimination, during making of alloy of small amounts of absorbed gases; these include H_2 and CO.

CABLES, ELECTRIC

STEEL-ALUMINUM. Steel-Aluminum Transmission-Line Cables (Stahl-Aluminiumleitungen), O. Scheller. Elektro Jl., vol. 7, no. 7, Apr. 10, 1927, pp. 117-120. Discusses physical and economic advantages of steel-aluminum lines over copper; reviews principal German patents on the subject.

STEEL-ALUMINUM. Strength Investigations for the Standardization of Steel-Aluminum Cables (Festigkeitsuntersuchungen zur Normung der Stahl-Aluminium-Seile), G. Berling and W. Rössler. V. D. I. Zeit., vol. 71, no. 25, June 18, 1927, p. 884. Determination of best cable construction and rules for calculation of tension and sag; tests were carried out by German General Electric Co. (A. E. G.), Gelten & Guilleaume, and Siemens-Schuckert works. Abstract from Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, no. 293.

CAR WHEELS

HEAT TREATMENT. Heat Treatment Eliminates Wheel Failures. Elec. Ry. Jl., vol. 70, no. 3, July 16, 1927, pp. 93-94, 4 figs. Process of hardening and tempering rolled-steel car wheels has been developed by Twin City Rapid Transit Company; wear is reduced and so far no failures have occured.

CASE HARDENING

IRREGULARITIES. Irregularities in Case Hardening. Metallurgist (Supp. to Engineer) June 24, 1927, pp. 85-87. Review of papers on this subject; although it appears that steels of similar composition do not harden equally under apparently identical conditions, it is not yet proved that they cannot be made to harden equally if suitable precautions are taken; there is no certain evidence to show that high-grade steel causes any difficulties during casing or hardening operations; irregularities under discussion are apparent in structural condition of carbide in certain steels after case-hardening.

NITRATION HARDENING. Nitration Hardening of Steel and Its Industrial Utilization (La nitruration des aciers et son utilisation industrielle), L. Guillet. Génie Civil, vol. 91, no. 2, July 9, 1927, pp. 38-43, 18 figs. Review of Fry's work and of investigations made by author; discusses industrial importance of this new remarkably simple case-hardening process.

OIL FUEL FOR. Oil Fuel for Carburizing, A. J. Smith. Petroleum Times, vol. 17, no. 441, June 25, 1927, pp. 1207-1208 and 1210. Results obtained in conjunction with continuous operation.

CAST IRON

CARBON REMOVAL. Removal of Elementary Carbon from Gray Cast Iron and Malleable Castings (Die Abscheidung von elementarem Kohlenstoff im grauen Gusseisen und im Temperguss), J. Bardenheuer. Giesserei-Zeitung, vol. 24, no. 13, pp. 365-366. Shows influence of graphite formation on strength properties of gray cast iron.

CHEMICAL ANALYSIS. Present and Future Status of Chemical Analysis of Cast Iron (Gegenwart und Zukunft der chemischen Analyse des Gusseisens), Wilke. Giesserei-Zeitung, vol. 24, no. 13, July 1, 1927, pp. 367-368. According to present status of chemical analysis, actual small constituents can be determined only with some percentage of errors.

GERMAN STANDARDS. Report of German Industrial Standards Committee (DIN Mitteilungen), W. Reichardt. Maschinenbau, vol. 6, no. 9, May 5, 1927, pp. 481-488. Proposed standards for cast iron, sheet steel, etc.

GRAPHITE IN. The Effect of Graphite on Structure of Gray Cast Iron (Die Wirkung der Graphitkeime auf die Gefügebeschaffenheit des Graugusses), H. Hanemann, Centralblatt der Hütten u. Walzwerke, vol. 31, no. 21, May 25, 1927, pp. 273-275, 8 figs. It is shown that effect of existing flakes on graphite crystallization are only apparent when cooling is sufficiently slow.

GROWTH. Growth of Cast Iron (Ueber das Wachsen von Gusseisen), W. Schwinning and H. Flössner. Stahl u. Eisen, vol. 47, no. 26, June 30, 1927, pp. 1075-1079, 11 figs. Discusses growth of machine castings after heating at 200 to 650 deg.

NICKEL AND CHROMIUM IN. On the Effect of Nickel and Chromium on the Strength Properties of Grey Cast Iron, E. Piwowarsky. Foundry Trade Jl., vol. 36, no. 568, July 7 and 14, 1927, pp. 4-6 and 37-41, 8 figs. Results of author's investigations. By causing cast iron having gray to mottled charge to solidify at first white to mottled by accelerated cooling, and graphitizing it only by subsequent annealing, mechanical strengths of range hitherto unreached were obtained.

NICKEL IN. Alloy Cast Iron Meets High Duty Requirements. Inco, vol. 7, no. 2, 1927, pp. 12-13, 4 figs. Use of nickel in cast iron produces substantially same improvements as in steel.

PIG IRON, INFLUENCE OF. Influence of the Quality of Pig Iron on Castings (De l'influence de la qualite des fontes en gueuses pour les moulages). Fonderie Moderne, vol. 21, June 25, 1927, pp. 178-181. Supplementary to article published in Apr. 10 issue of same journal; contains two contributions by J. Pascal and M. Boyer, respectively, on foundry problems of second melting, and quality of pig iron.

OXYGEN IN. Oxygen Existing in Pig and Cast Iron, Oberhoffer and Piwowarsky. Iron Age, vol. 120, no. 2, July 14, 1927, pp. 75-76. German tests give new light on an old problem; effect of temperatures and operating practice; new method of analysis for oxygen. Abstracted with comments, by Dr. R. Moldenke from Stahl u. Eisen, Mar. 31, 1927, p. 521.

CHAINS

CAST-STEEL. Cast-Steel Cable Chain. Foundry Trade Jl., vol. 35, no. 566, June 23, 1927, p. 532. Beardmore Foundry has produced finished cast-steel chain which has passed rigid test requirements laid down by British Admiralty.

COKE

SIMPLIFICATION. Consider Simplification of Coke, R. M. Hudson. Foundry vol. 55, no. 14, July 15, 1927, p. 569. Committee representing certain branches of foundry industry called on Division of Simplified Practice of U. S. Dept. of Commerce and requested that coöperative services of division be extended to foundry industry in an effort further to simplify and standardize grades, specifications, also methods of test for by-product coke for foundry purposes.

COPPER ALLOYS

MANGANESE-ALUMINUM. Magnetism and Crystal Structure of Manganese-Aluminum-Copper (Magnetismus und Kristallstruktur bei Manganaluminiumkupfer), F. Heusler. Zeit. für anorganische u. allgemeine Chemie, vol. 161, no. 1-2, Mar. 14, 1927, pp. 159-160. It is suggested that in manganese-aluminum-copper at red-heat aluminum atoms are completely dissociated from manganese and copper atoms, and remain so when mass is quenched; if alloy is aged at 80 deg. combination occurs between aluminum and copper atoms and between aluminum and manganese atoms, but without change in crystalline form, and metal becomes ferromagnetic.

CORROSION

COLLOIDAL CHEMISTRY AND. Relations between Colloidal Chemistry and Problems of Modern Corrosion Research (Wechselbeziehungen zwischen Kolloidchemie und den Fragen der modernen Korrosionsforschung), W. Beck. Korrosion u. Metallschutz, vol. 3, no. 4, Apr. 1927, pp. 73-79, 1 fig. Points out that corrosion process must in some way be dependent on sol formation, and if it is possible to keep sol, during its formation, separated from metal, corrosion would be hindered; results of tests. Bibliography.

STEEL SURFACES IN CONTACT. The Rusting of Steel Surfaces in Contact, G. A. Tomlinson. Royal Soc.—Proc., vol. 115, no. 771, July 1, 1927, pp. 472-483, 4 figs. When two machined steel surfaces are held firmly in contact and at same time are subject to vibration, it is often found on taking them apart that surfaces have become cemented together by production of relatively large quantities of oxide, and individual surfaces are badly pitted and have corroded appearance.

CRYSTALS

GROWTH. Theory of Crystal Growth (Zur Theorie des Kristallwachstums), H. Brandes. Zeit. für Physikalische Chemie, vol. 126, no. 3-4, Apr. 1927, pp. 196-210. Mathematical theory of crystal growth is developed for cubic, rhombododecahedral, and octahedral systems by considering energy conditions when new center of growth is formed on completed crystal surface.

MIXED. Formation of Mixed Crystals by the Contact of Solid Phases, and by Precipitation from Solution (Mischkristalle und ihre Bildung durch Kontakt fester Phasen und durch Fällung von Lösungen), L. Vegard and T. Hauge. Zeit. für Physik, vol. 42, no. 1, Mar. 28, 1927, pp. 1-14, 5 figs. Using Debye-Scherrer method, formation of mixed crystals by contact of solid phases, dried by phosphorus pentoxide, has been established for system KBr-KCl; evidence is thereby afforded for exchange of atoms between crystal gratings in contact.

STRUCTURE. Symmetry of Atoms in Crystals (Zur Frage nach der Symmetrie der Atome in den Kristallen), K. Herrmann. Zeit. für Physik, vol. 42, no. 8, May 3, 1927, pp. 631-636. Problem of symmetry of atoms in crystal structure is discussed with particular reference to views expressed in books by Schoenflies and Wyckoff, it is concluded that it is not necessary to ascribe hexagonal characteristic symmetry to atoms or ions in crystal.

CUPOLAS

COKE, INFLUENCE OF. The Properties of Coke Affecting the Cupola Melting of Steel, J. T. MacKenzie. Foundry Trade Jl., vol. 36, no. 568, July 7, 1927, pp. 15-18, 1 fig. Deals chiefly with total carbon absorbed by steel scrap when melted with various cokes of unusual collection, not complete, but well representative and containing extremes likely to be encountered.

PULVERIZED COAL AS SUPPLEMENTARY HEAT. Powdered Coal as Supplementary Source of Heat for Cupola Furnaces, U. Lohse. Eng. Progress, vol. 8, no. 6, June 1927, pp. 151-153, 10 figs. Recently powdered coal has been used as supplementary source of heat for melting furnaces in foundries, and results have been very satisfactory; in pulverizing plant employed for this purpose, charging hopper, iron separator, preliminary crusher, fine grinder, dust sifter, and dust conveyor were all combined in single machine; plant in question was built by Deutsche Babcock & Wilcox-Dampfkessel-Werke A.-G.

THEORY AND PRACTICE. Cupolas in Theory and Practice During Past Decade (Der Kupolofen in Theorie und Praxis der letzten Jahrzehnte), W. Mathesius. Giesserei-Zeitung, vol. 24, no. 13, July 1, 1927, pp. 357-359, 4 figs. Review of cupola melting tests carried out during past ten years, from which a complete theory of process of pig-iron melting in cupola is derived.

CUTTING METALS

UNDER WATER. Cutting Metals Under-Water, L. F. Hagglund. Am. Welding Soc.—Jl., vol. 6, no. 5, May 1927, pp. 51-54, 5 figs. Method of cutting by means of electric arc and oxygen; combines heat of electric arc, together with oxidizing effect of stream of gaseous oxygen; method has been used successfully at various depths down to 120 ft. to cut steel plate, sheet piling, cast steel, cast iron, copper and brass.

DIE CASTING

MACHINERY AND MATERIALS. Die Casting and Its Significance in Modern Technology (Spritzguss und seine Bedeutung für die neuzeitliche Technik), A. Amigo. Sparwirtschaft, nos. 4 and 5, Apr. and May, 1927, pp. 177-180 and 247-249, 11 figs. Old and new types of die-casting machines used in Germany and Austria; molds; economic aspect.

NON-FERROUS ALLOYS. Die Casting (Pressestobning), Ingeniören, vol. 36, no. 28, July 9, 1927, pp. 345-350, 7 figs. Reviews development of die casting of different alloys for various purposes; descriptions of several casting machines.

PROCESS. Die-Casting Process (Das Spritzgussverfahren, P. Schimpke. Stahl U. Eisen, vol. 47, no. 26, June 30, 1927, pp. 1069-1075, 7 figs. Basic principles of process; die-casting alloys; solidification process, casting molds and machines; fields of application.

PURCHASING. What to Know in Buying Die Castings, C. Pack. Iron Age, vol. 120, no. 3, July 21, 1927, pp. 140-141. First cost is not all-important element, considering that poor die will not give satisfactory results in user's product.

ELECTRIC FURNACES

ARC. Theories of Electric Arc Furnaces (Ueber die Theorien der elektrischen Lichtbogenöfen). Centralblatt der Hütten u. Walzwerke, vol. 31, no. 4, Jan. 26, 1927, pp. 37-38, 3 figs. Review of recent French and German investigations of energy regimen of electric furnaces as closed circuits, giving formulas and graphs.

CAST IRON. Gray Cast Iron From the Point of View of the Electrical Furnace, G. K. Elliott. West. Machy. World, vol. 18, no. 6, June 1927, pp. 279-281. Outlines main features of acid and basic electric furnaces, and effects of each upon principal elements of cast iron in comparison with effects obtained through cupola.

HARDENING. Hayes Globar Electric Furnace. Am. Mach., vol. 67, no. 2, July 14, 1927, p. 75. Particularly designed for hardening high-speed steel; made by C. I. Hayes, Providence R. I.; temperatures ranging from 1800 to 2500 deg. fahr., can be maintained continuously, and up to 2800 deg. fahr. in intermittent service.

HEAT-TREATING. Why the Electric Furnace for Heat Treating? W. J. Diederichs. Indus. Mgmt. (N. Y.), vol. 74, no. 1 July 1927, pp. 55-58, 4 figs. Factors that make this type of equipment desirable in modern tool room.

REHEATING. Brown Boveri Reheating Furnaces, G. Keller. Brown Boveri Rev., vol. 14, no. 6, June 1927, pp. 143-154, 17 figs. Framework for all reheating furnaces of type Gth is made in Brown Boveri workshops, and comprises strong rolled sections; temperature regulation; switchgear; pyrometers; field of application; economy of electric heat.

ROTATING-ARC. Theory of Rotating Electric Arc Furnace of the Evreinoff-Telny Construction (Ueber die Theorie des Elektroof-

ens mit rotierendem **Lichtbogen nach Evreinoff** und Telny), K. **von Kerpely. Centralblatt** der Hütten u. **Walzwerke, vol. 31, no. 22,** June 1, 1927, **pp. 293-296, 8 figs. Historical** review beginning **with 1893, mathematical** analysis of **recent designs.**

ELECTRIC WELDING, ARC

ABSORPTION-PLANT APPARATUS. Importance of Welding as Applied to Absorption Plant Apparatus, J. E. Kobernick. Nat. Petroleum News, vol. 19, no. 26, June 29, 1927, pp. 23-23. Tests by General Electric and Westinghouse companies have been made covering almost every phase of arc welding and records show welding to withstand fatigue that riveted joints can never endure.

ARC, FUNCTION OF. The Electric Arc and Its Function in the New Welding Processes, P. Alexander. Am. Welding Soc.—Jl., vol. 6, no. 6, June 1927, pp. 62-74. Metallic welding arc is a combination of three distinct features, namely, conduction of the electric current, melting of plate and deposition of metal from the rapidly melting electrode; atomic-hydrogen process; shielded-arc process; physics and chemistry of the crater, and welding in mixed gases.

MOTOR-TRUCK FRAMES. Welding Offers Economical Method of Reinforcing Truck Frames. Iron Trade Rev., vol. 81, no. 4, July 28, 1927, pp. 196-197, 2 figs. Simple method of welding reinforced web to I-beams of motor truck frames is adopted from the W. B. Boom entry in competition for the Lincoln Electric Co., Cleveland.

PLATES AND STRUCTURAL SHAPES. Welded Parts Take the Place of Castings, C. O. Herb. Machy. (N. Y.), vol. 33, no. 11, July 1927, pp. 861-865, 9 figs. Fabrication of plates and structural shapes into machine members by arc welding.

RAILWAY TIES. More Durable Than Wood, W. Dalton. Welding Engr., vol. 12, no. 7, July 1927, pp. 29-30, 5 figs. How unserviceable rails are converted into railroad ties by ingenious application of arc welding.

ROLLED STEEL. Rolled Steel Fabricated by Welding Displaces Castings in Machine Construction, R. H. Rogers. Gen. Elec. Rev., vol. 30, no. 7, July 1927, pp. 330-334, 11 figs. Rolled steel is stronger pound for pound; readily fabricated by metallic arc welding; greater freedom in machine design; quicker production; final product superior.

STEEL WINDOWS. Arc Welded Steel Windows, C. M. Rusk. Welding Engr., vol. 12, no. 7, July 1927, pp. 35-36, 2 figs. Welded structural iron window frames for new filtration plant for District of Columbia; twenty-eight window frames, all of 12 gauge steel construction, ranging in size from 6 feet by 10 feet to 20 feet by 27 feet.

STRUCTURAL STEEL. Arc Welding a 790-Ton Steel Structure, A. M. Candy. Elec. World, vol. 90, no. 4, July 23, 1927, pp. 157-162, 8 figs. 1¼ million-cu. ft. building at Sharon, Pa., field welded at $4.90 per ton, or 45 cents per weld-foot, and erected in five weeks; factors affecting training of welders; methods used; analysis of data.

STRUCTURAL STEEL. The Welding of Steel Structures. Machy. (N. Y.), vol. 33, no. 11, July 1927, pp. 825-827, 3 figs. Design, fabrication, erection, and cost of five-story shop, 70 ft. wide, 220 ft. long. Abstract of paper read before Am. Iron & Steel Inst.

ELECTRIC WELDING, RESISTANCE

SEAM. Seam Welding, W. H. Gibb. Am. Welding Soc.—Jl., vol. 6. no. 5, May 1927, pp. 55-64, 16 figs. Term "seam welding" is applied to that process of resistance welding by which overlapped edges of two pieces of sheet metal are joined in continuous weld, without addition of any other metal; advantages of process.

TRUCK WHEELS. Resistance Welding Truck Wheels, W. Remington. Am. Welding Soc.—Jl., vol. 6, no. 5, May 1927, pp. 64-73, 10 figs. Welding of Bethlehem rolled-steel truck wheel.

FORGE SHOPS

DODGE AUTOMOBILE PLANT. Dodge Forge and Heat Treating Plant, C. Longenecker. Forging-Stamping-Heat Treating, vol. 13, no. 5, May 1927, pp. 174-177, 2 figs. New plant of Dodge Brothers, Inc.; routing of material; fuel supply and distribution. Exemplifies latest practice in design and equipment; efficient lighting and ventilation; furnaces and hammers located to facilitate movement of material. Heat treating, cleaning, and pickling performed on large scale production; "safety first" given adequate attention.

NON-FINANCIAL INCENTIVES IN. The Value of Non-Financial Incentives in the Forge Shop, J. Thompson. Forging-Stamping-Heat Treating, vol. 13, no. 6, June 1927, pp. 228-230. Discussion of inducements, other than wages, which affect a workman's attitude toward his word and result in increased interest and efficiency.

FORGING

FLOW OF METALS IN. The Flow of Metals in Forging. Forging-Stamping-Heat Treating, vol. 13, no. 7, July 1927, pp. 248-252, 2 figs. To secure maximum strength and durability parts should be so formed that "flow lines" are in correct position; methods of etching.

UPSET PROCESS. Forging by The Upset Process, J. C. Kielman. Forging-Stamping-Heat Treating, vol. 13, no. 6, June 1927, pp. 208-211. Forging rings by upset process; use of right steel for forging dies and proper heat treatment essential for long service.

FOUNDRIES

STEEL, PHRASEOLOGY. Steel Foundry Phraseology. Research Group News, vol. 4, no. 2, July 15, 1927, pp. 137-140. Presents and defines terms with which users of steel castings may become acquainted to their advantage, in desired better familiarity with shop practices, encouraged by progressive steel founders; terms relating to equipment, molding, metal and defects.

FUEL ECONOMY

POSSIBILITIES. Possibilities of Fuel Economy, H. A. Brassert. Iron Age, vol. 120, no. 2, July 14, 1927, pp. 77-78. Suggests improvements in iron and steel industry; Germans lead in heat-saving refinements; gas en-

richment proposed. Abstract of paper read before Eastern States Blast Furnace and Coke Oven Assn.

FURNACES, HEATING

HEAT TRANSFER IN. Heat Transfer in Continuous Furnaces. Fuels & Furnaces, vol. 5, no. 7, July 1927, pp. 857-858, 2 figs. Information on heat transfer in continuous furnaces of pusher type recently obtained by Heat Economy Bur. of German Iron & Steel Inst., who made series of tests in connection with coal-fired continuous furnace used for heating cold blooms.

FURNACES, INDUSTRIAL

CAR-TYPE. New Design Car Type Furnace Used in Manufacture of Battery Plates, W. M. Smith. Fuels & Furnaces, vol. 5, no. 7, July 1927, pp. 875-877, 4 figs. Furnaces are used for baking of copper oxide plates, operation requiring temperature of about 2000 deg. fahr.

DESIGN. Practical Industrial Furnace Design, M. H. Mawhinney. Forging-Stamping-Heat Treating, vol. 13, no. 7, July 1927, pp. 271-275, 1 fig. Enumeration of several channels through which heat is lost; calculations for electric furnaces; rate of heating and methods for saving heat.

FURNACES, MELTING

CRUCIBLE-STEEL. Practical Crucible-steel Melting, J. F. Kayser. Mech. World, vol. 81, no. 2108 and 2109, May 27 and June 3, 1927, pp. 381-382 and 399-400. Deals with coke-fired and producer-gas fired crucible-steel furnaces; most economic furnaces are fired with producer-gas; ingredients for crucible-steel.

TAR-OIL-BURNING. Melting Furnaces Fired with Tar Oils (Schmelzöfen für teerölfeuerung), Werkstattstechnik, vol. 21, no. 9, May 1, 1927, pp. 260-263, 9 figs. Describes low pressure "Schmidt" burner, simple in construction and control, especially adapted for fuel oils difficult to gasify; its installation in combination with various types of small smelting furnaces.

FURNACES, STEEL-TREATING

GAS-FIRED. Building Steel Treating Furnaces, D. Mitchell Duncan. Can. Machy., vol. 37, no. 26, June 30, 1927, pp. 67-69, 3 figs. Requirements of modern gas-fired furnace and steps taken by progressive manufacturers to meet problems of finer temperature control.

GAS MAINS

WELDED. Expansion and Contraction of Welded Gas Lines, F. M. Lege, Jr., Am. Welding Soc.—Jr., vol. 6, no. 5, May 1927, pp. 36-38. Methods of providing for slack in line; manner in which large-diameter welded gas line is placed in ditch, with regard to compression, is of equal or greater importance than are good welds.

GOLD

ADMIXTURES. Influence of Small Admixtures of Bismuth, Lead, Tin, etc., on Structure and Workability of Gold and Gold-Alloys [Ueber den Einfluss geringer Beimengungen (Bi, Ph, Sn, usw) auf das Gefüge und die Bearbeitbarkeit von Gold und Goldlegierungen], L. Nowack. Zeit. für Metallkunde, vol. 9, no. 6, June 1927, pp. 238-244, 41 figs. Deals with alloys of gold and silver, gold and copper and silver-copper gold alloys, and alloys of gold with platinum, palladium or nickel; investigation showed that additions of metals even in small quantities change structure of gold and its alloys considerably.

HARDNESS

BRINELL TEST. Need Shown for Changed Brinell Hardness Test Methods. Automotive Industries, vol. 57, no. 3, July 6, 1927, pp. 88-89, 5 figs. Investigation shows that in tests measurements should be made while ball is under load; elasticity of metal influence results otherwise.

THEORY OF. Theory of Hardness (Beitrag zum Härteproblem), G. Sachs. Zeit. für Technische Physik, no. 4, 1927, pp. 132-141, 22 figs. Report on experiments with iron and copper, made at Kaiser Wilhelm Inst. of Berlin, to verify Prandtl theory; results are in accord with theory of elasticity.

HOUSES

STEEL. Steel-Framed Dwelling Electrically Welded, J. G. Dudley. Iron Age, vol. 120, no. 3, July 21, 1927, pp. 135-137, 4 figs. Stucco combined with steel to meet problems of non-combustible house construction; all joints tack-welded at job.

STEEL. Steel-Wall Dwelling Houses (Wohnhäuser nach dem Stahlwandsystem), A. Schmid. Zeit. des Oesterr. Ingenieur u. Architekten-Vereines, vol. 79, no. 19-20, May 13, 1927, pp. 174-176, 4 figs. Plans and photographs of interior of recent German and Austrian types of small city dwellings and week-end country cottages.

IRON

CEMENTATION. Progress in Producing Steel from Soft Iron (Ein wesentlicher Fortschritt in der Erzeugung von Stahl auf Weicheisen), W. Beck. Werkstattstechnik, vol. 21, no. 9, May 1, 1927, pp. 253-254. New Durferrit cyanogen compound can be used at temperatures of 120 deg. cent. higher than present practice accelerating speed of cementation as much as eight times.

DIRECT REDUCTION. The Direct Reduction of Iron (Die direkte Erzeugung des Eisens), F. Wüst. Stahl u. Eisen, vol. 47, nos. 22 and 23, June 2 and 9, 1927, pp. 905-915 and 955-965, 27 figs. partly on supp. plates. Discusses phenomena of direct and indirect reduction (processes of Edwin, Wibers, of Bureau of Mines and of Hornsey); comparison of different processes.

MICROSTRUCTURE. Some Unusual Microstructures in Iron, F. S. Tritton. Metallurgist (Supp. to Engineer), June 24, 1927, pp. 88-90, 6 figs. Microstructures observed in specimens of iron during course of metallurgical research in modern laboratory, illustrating that iron still exhibits some phenomena that are not well known or understood.

RECRYSTALLIZATION. Behavior of Nuclei During the Recrystallization of Metals (Das Wesen der Rekristallisationskerne bei Metallen), A. E. van Arkel and P. Koets. Zeit. für Physik, vol. 41, no. 8-9, 1927, pp. 701-707, 5 figs. Recrystallization can commence at grain fragments which have been

left undisturbed by deformation, or which are least disturbed or else at nuclei which form spontaneously during heat at points of maximum disturbance; authors attempt to decide between these two views by experiments on deformed alpha iron which is subsequently annealed just below and just above alpha-gamma transformation; shows that "recrystallization nuclei" are essentially same as "transformation nuclei" and speaks for validity of second viewpoint. See brief translated abstract in Min. & Met., vol. 8, no. 247, July 1927, p. 320.

IRON ALLOYS

FOUNDRY, ANALYSIS. New Method For Quantitative Analysis of Foundry Iron (Nouvelle méthode d'analyse quantitative des ferres de fonderie), O. Macchia. Fonderie Moderne, vol. 21, July 10, 1927, pp. 197-198. Difference between this method and those commonly employed consist in determination of magnesium, lime, iron and aluminum; determination of these four constituents is gravimetric.

IRON-CARBON. Ternary Systems with Iron and Carbon (Ueber Dreistoffsysteme mit Eisen und Kohlenstoff), F. Sauerwald, H. Neudecker and J. Rudolph. Zeit. für anorganische u. allgemeine Chemie, vol. 161, no. 3, Apr. 5, 1927, pp. 316-320. Iron, carbon and chromium in proportions required for making compound Fe_3C, Cr_4C, which is alleged to occur in chromium steels, were melted together and microstructure of alloy was examined; whether slowly cooled or annealed for long period and quenched, this alloy invariably exhibits duplex structure, and, after powdering finely, can be separated into magnetic and non-magnetic fraction.

IRON-PHOSPHORUS. Study of the Systems Iron-Phosphorus, Iron-Silicon, and Iron-Phosphorus-Silicon (Beiträge zur Kenntnis der Systeme Eisen-Phosphor, Eisen-Silizium und Eisen-Phosphor-Silizium), H. Hanemann and H. Voss. Centralblatt der Hütten u. Walzwerke, vol. 31, nos. 19, 20 and 22, May 11, 18 and June 1, 1927, pp. 245-248, 259-262 and 287-289, 24 figs. Critical review of earlier, mostly English work, and report of verification experiments and of metallographic and X-ray studies of mixed iron crystals made at Laboratory for Iron Metallurgy at Berlin Technical Institute. May 18; Binary system, iron-silicon, in concentrations of 15 to 33.6 per cent. June 1; Ternary system, iron-phosphorus silicon.

IRON CASTINGS

IMPROVEMENTS. Influence of Iron Castings on Progressive Engineering, Foundry Trade Jl., vol. 35, no. 566, June 23, 1927, pp. 521-524. Author believes answer to problem of improving iron castings is to be found in practical results now available, due to lengthy, expensive and successful practical research work which has been done on Continent during last 10 years; refers to Diefenthaler process for production of pearlitic cast iron and Emmel process of producing iron castings from cupola charges containing up to 90 per cent of steel scrap.

MACHINED. Why Machined Castings Change Shape, F. E. Cardullo. Machy. (N. Y.), vol. 33, no. 12, Aug. 1927, pp. 905-906, 3 figs. Causes of change in castings; effect of removing stressed metal; cause of distortion often misunderstood; effect of stresses from peening flat surfaces.

LEAD ALLOYS

LEAD - ANTIMONY - ARSENIC. Ternary System Lead-Antimony-Arsenic (Uber das ternäre System Blei-Antimon-Arsen), E. Abel and O. Redlich. Zeit. für anorganische u. allgemeine Chemie, vol. 161, no. 3, Apr. 5, 1927, pp. 221-227. System belongs to type in which two of constituents (arsenic and antimony) form continuous series of solid solutions which are insoluble in third constituent (lead) but form eutectic with it; eutectic melts at 252 deg. when arsenic predominates.

MAGNESIUM

COMMERCIAL POSSIBILITIES. Magnesium. Metallurgist (Supp. to Engr.), June 24, 1927, pp. 81-82. Improvement of magnesium and its alloys, or of their treatment in regard to corrosion resistance stands in forefront of problems to be solved before serious advances can be made with those metals; it is, however, problem for investigator which should not prove ultimately beyond solution.

MALLEABLE IRON

WHITE-HEART. The Influence of Manganese and Manganese Sulphide on Whiteheart Malleable, E. R. Taylor. Foundry Trade Jl., vol. 36, nos. 568 and 569, July 7 and 14, 1927, pp. 23-24, and 41-44, 10 figs. Sulphur and manganese in black heart; influence of sulphur in white-heart malleable. Influence of manganese and manganese sulphide; influence of sulphide on fracture; loss or gain of sulphur during annealing.

MANGANESE ALLOYS

MANGANESE-ZINC. Binary System Manganese-Zinc (Ueber das Zweistoff-System Mangan-Zink), C. L. Ackermann. Zeit. für Metallkunde, vol. 19, no. 5, May 1927, pp. 200-204, 16 figs. Critical discussion of diagrams of state of Parravano, Siebe, and Gieren; development of a new diagram; strain hardening of zinc through small additions of manganese with regard to hardness, compressive strength and impact resistance.

MANGANESE STEEL

OPEN-HEARTH. Announces Free Cutting Open-Hearth Steel. Iron Trade Rev., vol. 81, no. 2, July 14, 1927, p. 81. Union Draw Steel Co., Beaver Falls, Pa., has introduced high-manganese steel in which qualities of machinability credited to bessemer screw stock is combined with desirable physical properties of well-made open-hearth steel.

METAL DRAWING

COLD WORKING. Deformation Resistance of Cold Drawing (Der Formänderungswiderstand des Kaltziehens in Abhähgigkeit von Abnahmeverhältnis und Ziehwinkell, O. L. Weib. Zeit. für Metallkunde, vol. 19, nos. 2 and 3, Feb. and Mar., 1927, pp. 61-67 and 94-100, 22 figs. Results of tests show that deformation resistance is dependent on drawing angle and reduction ratio; variability of deformation resistance can only be

determined in relation to flow pressure and coefficient of friction; describes method of determining flow pressure.

METALLURGY

APPLICATION TO ENGINEERING TROUBLES. The Metallurgical Side of some Engineering Troubles, H. J. Young. Inst. Marine Engrs.—Trans., vol. 39, July 1927, pp. 279-296 and (discussion) 296-308, 24 figs. Few instances of common troubles where money can be saved and progress made by employment of trained methods of investigation and control.

METALS

CORROSION. Problems of Corrosion Research at 1926 Meeting of National Committee for Metal Protection (Probleme der Korrosionsforschung und des Metallschultzes auf der Jahresversammlung 1926 des Reichsausschusses fur Metallschutz), J. Hausen. Zeit. für Flugtechnik u. Motorluftschiffahrt, vol. 9, no. 18, May 14, 1927, pp. 201-203, 7 figs. Duffek spoke about corrosion of quality steels; conclusion is drawn that slag inclusions etc. on surface further corrosion by formation of local voltage differences; in case of aluminum, scratches etc. promote solution of metal and polish helps considerably to prevent it; silicon segregations in aluminum also promote corrosion; in consequence hereof heat treatment may promote corrosion by leading to segregation of crystals; best heat-treating temperatures are 400 to 500 deg. cent.; Tracknitz stated that duralumin was quite resistant to atmospheric influence on shore but not so resistant to sea water; white corrosion products which form on its surface must be rapidly removed as they greatly promote further corrosion; tests such as Mylius oxydic salt test do not give dependable indications; susceptibility to corrosion can be judged by decrease in durability caused by exposing one side of sheet sample to corrosive action; bloom gave discussion about paints; best pigments are those which form well distributed layer of grains of varying sizes. See brief English abstract in Automotive Abstracts, vol. 5, no. 7, July 20, 1927, p. 218.

CORROSION. The Intercrystalline Corrosion of Metals, H. S. Rawdon. Metal Industry, (Lond.), vol. 30, no. 26, July 1, 1927, pp. 647-651, 6 figs. Intercrystalline corrosion as related to microstructural features of metal; behavior of lead; sheet duralumin; die castings; combined effect of stress and corrosion in producing intercrystalline brittleness; season crackling of brass.

DEFORMATION AND STRESS DISTRIBUTIONS. Surface Deformations and Stress Distribution in Tensile Test Pieces (Les déformations superficielles et la distribution des efforts dans les éprouvettes de traction), Génie Civil, vol. 91, no. 1, July 2, 1927, pp. 10-13, 28 figs. Studies by Ch. Frémont which explain formation of lines in tensile test pieces and which permit deduction of method of investigation of stress distribution in metals.

FRACTURE. Cause of Formation of Internal Hollow Spaces in the Rupture of Tensile Test Pieces (La cause de la formation de la coupelle, dans la rupture des éprouvettes essayées à la traction), Fremont. Génie Civil, vol. 90, no. 19, May 7, 1927, pp. 453-456, 47 figs. Results of investigation of this type of fracture.

PICKLING. Practical Application of Inhibitors in Pickling Operations, F. N. Speller and E. L. Chappell. Chem. & Met. Eng., vol. 34, no. 7, July 1927, pp. 421-423, 4 figs. Addition of small quantities of various organic substances shown to result in saving of acid, to preserve metal surface and to reduce fumes.

REACTIONS WITH SOLID SALTS. Reactions of Metals with Solid Salts on Heating (Reaktionen von Metallen mit festen Salzen beim Erhitzen), B. Garre. Zeit. für anorganische und allgemeine Chemie, vol 161, no. 1-2, Mar. 14, 1927, pp. 108-112. Heating curves of mixtures of various metallic oxides and carbonates with magnesium and aluminum, respectively, have been determined; reactions with magnesium start more gradually and at lower temperature than those with aluminum; with binary mixtures of zinc and tin with lead oxide or cupric oxide, or of cupric oxide with lead or nickel reaction commences below melting point of either component.

RECRYSTALLIZATION. Recrystallization of Metals (Versuche über die Rekristallisation von Metallen), R. Karnop and G. Sachs. Zeit. für Physik, vol. 42, no. 4, Apr. 4, 1927, pp. 283-301, 34 figs. For varieties of aluminum rods 5 mm. in diameter after mechanical deformation by stretching, tensile strength as function of temperature has been determined for stretched copper strips before and after recrystallization and extensibility of copper strip before and after recrystallization has been measured in same temperature range. See brief translated abstract in Brit. Chem. Abstracts, June 1927, p. 504.

ROLLED AND RECRYSTALLIZED. Texture of Rolled and Recrystallized Regular Surface-Centered Metals (Walz- und Rekristallisationstextur regulär flächenzentrierter Metalle), V. Göler and G. Sachs. Zeit. für Physik, vol. 14, no. 11-12, Mar. 14, 1927, pp. 873-888, 27 figs. Crystalline structure of rolled and of recrystallized aluminum and copper sheet has been examined by X-ray method and results obtained are discussed.

MONEL METAL

STEAM TURBINE BLADES. Monel Metal for Steam Turbine Blades (L'emploi du metal Monel pour l'ailettage des turbines à vapeur). Génie Civil, vol. 90, no. 17, Apr. 23, 1927, pp. 416-417. Monel metal is used extensively for blades of steam turbines; its tensile strength ranges from about 35 to 40 tons per sq. in, with extension of 30 per cent and elastic limit is between 22 and 27 tons per sq. in.; there is only small decrease in strength at temperatures concerned in steam turbines, and metal resists oxidation and pitting; data concerning experience with typical Monel-metal blades in marine and land turbines.

NICKEL

CANADA. Nickel—Past and Present, R. C. Stanley. Can. Min. & Met.—Bul., no. 183, July 1927, pp. 844-877, 3 figs. Early history; market development in post-war period; present industrial uses of nickel; forms of nickel commercially available; typi-

cal compositions of industrial nickel products; principal industrial uses of nickel and nickel products. Bibliography.

ORE. Nickeliferous Rocks From The Society Islands. Bul. of Imperial Inst., vol. 25, no. 2, July 1927, pp. 129-130. Report on some samples from Society Islands.

NICKEL ALLOYS

MELTING. Melting Nickel Alloys, J. A. Duncan. Metal Industry (N. Y.), vol. 25, no. 7, July 1927, p. 280, 2 figs. Pouring of high-temperature metal castings improved by gas.

MOND NICKEL. Contribution on "Mond Nickel." Inst. Mar. Engrs.—Trans., vol. 39, June 1927, pp. 254-259. Presents charts showing various stages in production from its ore of well-known Mond Nickel, purest form of this metal which is produced commercially today; uses of ferrous and non-ferrous nickel alloys.

NICKEL STEEL

NICKEL-CHROMIUM-MOLYBDENUM. The Properties of Some Nickel-Chromium-Molybdenum Steels, J. H. Andrew, M. S. Fisher and J. M. Robertson. Iron & Coal Trades Rev., vol. 114, no. 3092, June 3, 1927, pp. 892-893. Deals with properties of two series of steels; in both series percentages of chromium and molybdenum were constant, and nickel increased from 2 to 5 per cent; thermal data; mechanical properties. Abstract of paper read before Iron and Steel Inst.

NON-FERROUS METALS

CASTINGS, STRESSES IN. Stresses in Non-Ferrous Castings, C. H. Desch. Metal Industry, (Lond.), vol. 31, no. 2, July 15, 1927, pp. 28-30, 3 figs. Contraction data of chief metals; brittle range; intercrystalline stress; beta brass structure. Paper read at Institute of British Foundrymen.

MIRAMANT. Miramant. Eng. Progress, vol. 8, no. 6, June 1927, p. 167. High grade non-ferrous alloy for metal-cutting tools has natural hardness that does not show slightest change or deterioration at softening or melting temperatures of steel; melting point of mirament is approximately 2100 deg. cent. and its softening temperature about 200 deg. less.

SPREAD IN ROLLING. Spread in Rolling of Certain Non-Ferrous Metals (Zur Frage der Breitung bei einigen Nichteisen-Metallen), W. Tafel and F. Anke. Zeit. für Metallkunde, vol. 9, no. 6, June 1927, pp. 225-231, 8 figs. Temperature measurements in rolling mills; efficiency of wire-rod mill for copper and aluminum; rule-of-thumb formula for spreading of quadratic and rectangular section; spreading is not linear function of pressure; influence of rolling speed, role diameter, initial width and rolling temperature on spreads; it is claimed that Siebel's formula for spread gives best agreement with results.

OPEN-HEARTH FURNACES

DESIGN AND OPERATION. Effect of Design and Construction Upon Operation of the Open Hearth Furnace, W. Trinks. Fuels & Furnaces, vol. 5, nos. 1, 2, 3 and 4, Jan., Feb., Mar. and Apr., 1927, pp. 33-36, 175-176, 307-310 and 477-482, 3 figs. Jan.: Factors which influence cost of making steel, such as raw materials, investment, labor, fuel, repairs and maintenance. Feb.: Refractories used in open-hearth furnace construction and their suitability. Mar. Features of open-hearth furnace design upon which depend production and control of high flame temperature, high radiating qualities of flame and control of direction of flame. Apr.: Heat requirements; character of flame which will give best results; combustion devices.

100-TON. Dimensions of 100-Ton Open-Hearth Furnaces (Abmessungen von 100-t-Siemens-Martin-Oefen), M. Pavloff. Stahl u. Eisen, vol. 47, no. 23, June 9, 1927, pp. 953-955. Rules for dimensioning of 100-ton furnaces, based on furnaces of average and smaller size, taking into consideration changed conditions, such as fuel consumption, etc.

REGENERATORS. Heat Recovery in Open Hearth Furnaces, W. Trinks. Fuels & Furnaces, vol. 5, no. 7, July 1927, pp. 851-853, 2 figs. Use of regenerators in open-hearth furnaces; size of regenerators; increasing efficiency of checkerwork; minimizing heat losses.

OXYACETYLENE WELDING

ALUMINUM SHEETS. Welding of Aluminum Sheets Used in the Construction of Pierce Arrow Bodies, F. E. A. Klein and G. C. Hoff. Am. Welding Soc.—Jl., vol. 6, no. 5, May 1927, pp. 34-36. Advantages of using oxyacetylene welding process in construction of automobile bodies made of aluminum sheets.

CAST-IRON PIPE. Welding Cast Iron Pipe. Acetylene Jl., vol. 29, no. 13, July, 1927, pp. 19-23 and 28. Investigation of bronze-welded lines shows need of careful laying procedure and desirability of expansion joints at 100-foot intervals.

MATERIALS FOR. Selection of Materials for Welding, E. E. Thum. Am. Welding Soc.—Jl., vol. 6, no. 5, May 1927, pp. 38-43. For good results in oxyacetylene welding, as in any other activity, it is necesasry to select raw materials on which to work; some low-carbon steels are not satisfactory for welding; these steels boil with more or less violence when melted under oxyacetylene flame, throwing off great many sparks at time.

PIPE LINES. The Welding of the Mokelumme Pipe Line, L. T. Jones and W. S. Weeks. Am. Welding Soc.—Jl., vol. 6, no. 6, June 1927, pp. 7-26 and (discussion) 27-38, 27 figs. Results of a detailed study of the acetylene welding of the pipe line.

TANKS. Oxyacetylene-Welded Construction of a Large High-Pressure Storage Tank, H. E. Rockefeller. Am. Welding Soc.—Jl., vol. 6, no. 5, May 1927, pp. 16-32, 12 figs. Construction of ethylene storage tank, constructed for Carbide and Carbon Chemicals Corp.; method of welding this tank.

PIPE, CAST-IRON

IMPROVEMENTS. Recent Developments in Cast-Iron Pipe, H. Y. Carson. Can. Engr., vol. 52, no. 26, June 28, 1927, pp. 633-634, 8 figs. Improvements in pipe manufacture; casting pipe by centrifugal process; bronze-welding broken mains; cement-lined pipe. Paper presented at Am. Water Works Assn.

PYROMETRY

DEVELOPMENTS AND METHODS. Recent Progress in Pyrometry (Les progrès récents en pyrométrie) J. Cournot. Chaleur & Industrie, vol. 8, no. 86, June 1927, pp. 317-323, 8 figs. Shows development of pyrometers and numerous advantages in using these apparatus; expansion, thermoelectric, resistance, radiation and optical methods; automatic regulation of furnaces.

RAILS

JOINTS, WELDED. N. Y. C. Tries Welded Joints in Paved City Street. Ry. Eng. & Maintenance, vol. 23, no. 8, Aug. 1927, pp. 330-332, 9 figs. Experiments in Thermit welding of rail joints in paved city street conducted by New York Central during 1926; owing to apparently satisfactory results obtained, further installation of welded joints is being made in hope of obtaining better track conditions and longer rail life, with more economical maintenance.

STEEL. Steel Rails, C. W. Gennet, Jr. New England Ry. Club—Proc., Apr. 12, 1927, pp. 77-86 and (discussion) 86-96. Examines modern rail-making methods drawing comparisions with practice 30 or 40 years ago; problems of steel rails.

SURFACE HARDENING. Automatic Heat and Cold Work Surface Hardening of Rails in Service, Sabouret. Int. Ry. Congress Assn.—Bul., vol. 9, no. 6, June 1927, pp. 510-532, 15 figs. Accident owing to rail fracture at Grisolles; appearance of cracks and investigation thereof; superficial hardening by heat or mechanical action; facts and inquiry into causes; remedies. Translated from Générale des Chemins de Fer.

WEAR. The Problem of Railway Wear. Ry. Engr., vol. 48, no. 570, July 1927, pp. 278-279. Facts indicate that mere carbon hardness is not prime requisite in steel-rail composition, but that manganese plays a greater part than carbon in producing that toughness that is best fitted to withstand peculiar combination of pounding and rubbing which rail suffers when in service; specified "higher carbon" compositions of British Standard Specifications should be subdivided, and definite manganese percentages specified, somewhat after this fashion.

REFRACTORIES

INDUSTRIAL FURNACES. Troubles of the Furnace Builders with Refractories. Forging—Stamping—Heat Treating, vol. 13, no. 6, June 1927, pp. 231-233. Conditions that exist in certain types of furnaces are considered, together with character of refractories that will meet these conditions; deals with underfired normalizing furnaces, enameling furnaces, brass-melting furnaces.

ROLLING MILLS

BLOOMING MILLS. Blooming Mill Given Electric Drive. Iron Age, vol. 120, no. 4, July 28, 1927, pp. 203-204, 1 fig. Reversing motor of 4000 hp. installed by Bourne-Fuller Co.; better product reported at lower cost.

BLOOMING MILLS. New Three-High Blooming Mill at the Works of Societa Italiana Ernesto Breda, Milan. Iron & Coal Trades Rev., vol. 14, no. 2095, June 24. 1927, pp. 994-995, 5 figs. Designed to roll blooms weighing up to 2 tons; electric driving equipment; roll adjustment; lifting-table equipment; bloom tilting and shifting device.

FURNACES. Reconstruction of Rolling-Mill Furnaces at Works of A.-G. Phœnix in Ruhrort, Germany (Umbauten der Walzwerksöfen bei der A.-G. Phœnix in Ruhrort), C. Mettegang. Stahl u. Eisen, vol. 47, no. 25, June 23, 1927, pp. 1033-1047, 27 figs. Reconstruction of recuperative into regenerative furnaces; ingot-heating furnaces for small and medium-section mills; advantages of pure coke-gas over mixed-gas firing.

LUBRICATION. Lubricating Continuous 10-Inch Merchant Bar Mill, W. A. Reynolds. Iron Trade Rev., vol. 81, no. 2, July 14, 1927, p. 83. Mill has complete pressure-oiling system.

SHEET BAR AND SKELP. New Sheet Bar and Skelp Mill at Indiana Harbor, A. E. Beardmore. Iron & Steel Engr., vol. 4, no. 7, July 1927, pp. 342-345, 7 figs. Continuous mill has recently started production at Indiana Harbor Plant of Youngstown Sheet & Tube Company.

SHEET MILLS. Continuous Sheet Mill at Ashland, Ky., C. Longenecker. Blast Furnace & Steel Plant, vol. 15, no. 7, July 1927, pp. 335-338, 9 figs. Methods involved are explained, from casting of ingot to finished sheet.

SHEET MILLS. Exceeds Ton of Sheets Per Minute. Iron Age, vol. 119, no. 24, June 16, 1927, pp. 1731-1737 and 1792, 5 figs. Armco continuous mill at Ashland, Ky., is epoch-making as to productivity and unique in incorporating rolling principles established by special research; equipment for continuous production of sheet. See also description in Iron Trades Rev., vol. 80, nos. 24, 25, 26, and vol. 81, nos. 1 and 2, June 16, 23, 30, July 7 and 14, 1927, pp. 1532-1535, 1593-1596, 1656-1659, 8-12 and 67-70.

SHEET MILLS. Minimizes Heating Costs of Steel Sheets, F. W. Manker. Iron Trade Rev., vol. 81, no. 4, July 28, 1927, p. 200, 1 fig. Development of new and modern equipment for efficient and economical utilization of gas fuel at plant of the West Penn Steel Co., Brackenridge, Pa.; soaking pits, sheet and pair furnaces, box annealing furnaces and drying ovens all are fired with gas.

SOAKING PITS. Soaking Pit with Recuperator. Blast Furnace & Steel Plant, vol. 15, no. 7, July 1927, pp. 347-349, 2 figs. Recuperation applied to "pits" in European plants with satisfactory results; installation in American mill increases efficiency; advantages pointed out.

STRUCTURAL STEEL. Carnegie Structural Mill at Homestead, R. H. Wright. Blast Furnace & Steel Plant, vol. 15, no. 7, July 1927, pp. 331-334. By electrical appliances, mills at Munhall are started from New York City; production of steel outlined; project involves complete reconstruction of department used in porduction of structural steel.

WIRE-ROD. Making of Wire Rods, G. A. Richardson. Wire, vol. 2, no. 7, July 1927, pp. 230-232, 6 figs. Improved methods and machinery in Sparrows Point plant of Bethlehem Steel Co.

ROLLS

RAGGING. "Ragging" of Rolls (Walzenschärfen), H. Cramer. Stahl u. Eisen, vol. 47, no. 14, Apr. 7, 1927, pp. 582-586, 10 figs.; also translation in Blast Furnace & Steel Plant, vol. 15, no. 7, July 1927, pp. 326-328, 10 figs. Efficiency of rolls increased by "ragging"; best form of "ragging"; relation of speed of rolls, ingot and lapping of "ragging"; explanation of lapping.

WEAR OF. Wear of Blooming-Mill Rolls, H. Cramer. Iron & Coal Trades Rev., vol. 115, no. 3098, July 15, 1927, pp. 96-98, 9 figs. Wear of rolls in service is made good by turning them down; to restore original width in worn roll passes are cut with sloping sides, thus tapering off rolls to certain extent; one way of minimizing quantity of roll metal to be removed is described for three-high blooming mill. Translated from Stahl u. Eisen.

SCRAP

UTILIZATION. Recent Practice in Utilization of Iron-Containing Slag of Metallurgical Plants (Neuere Erfahrungen aus der Verwertung eisenhaltigen Schuttes), H. Hermanns. Wärme, vol. 50, no. 16, Apr. 22, 1927, pp. 283-387, 9 figs. German installations for recovering iron from waste slag heaps by means of separators and pole piece magnetic drums.

SILVER

DEFECTS IN. Defects in Silver-Copper Alloys (Krankheitserscheinungen am Silber (Blasensilber, Blausilber) und blasenfreies Silber, S. Streicher. Zeit. für Metallkunde, vol. 19, no. 5, May 1927, pp. 205-210, 9 figs. Majority of defects are traced to original slab or ingots, and resemble in many ways defects familiar in brass strip or sheets, that is, blisters and "spill". See translated abstract in Metallurgist (Supp. to Engineer), June 1927, p. 94.

STAYBOLTS

HOLLOW BARS. Seamless Hollow Rolled Staybolt Bars. Boiler Maker, vol. 27, no. 7, July 1927, p. 200, 3 figs. Patented process to manufacture on production basis hollow staybolt iron; process consists essentially of building up hollow fagot by arranging rods around hollow metal core, heating fagot to welding and rolling temperature, rolling heated fagot down to required size, at same time preserving desired direction of hole through axis of bar.

STEEL

AUTOMOBILE PARTS. Defects and Fractures in Automobile Parts and Their Metallographic Appraisal (Fehler und Brüche an Kraftfahrzeugteilen und ihre metallographische Beurteilung, M. Schwarz. Zeit. des Bayerischen Revisions-Vereins, vol. 31, nos. 5 and 6, Mar. 15 and 31, 1927, pp. 46-48 and 62-65, 53 figs. on supp. plates. Deals with permanent fractures caused by repeated stresses, violent fractures due to single overstresses and fractures that lie between these two extremes, caused by repeated over-stepping of normal working stresses; each of these is discussed.

BALL BEARINGS. Steel for Ball Races. Metallurgist (Supp. to Engineer), June 24, 1927, p. 83. Review of paper by Houdremont and Kallen, published in V. D. I. Zeit., July 31, 1926, on preparation and properties of ball-bearing steels; basic electric furnace is to be preferred to basic open-hearth, but it is preferable to work with pure scrap or Swedish charcoal iron; whole process resolves itself into melting charge and adding alloy constituents, either in acid or basic open-hearth or electric furnaces; addition of chromium to steel causes marked increase of hardness and elastic limit.

CONVEYOR CHAINS. Researches on Conveyor Chains for Open Cut Lignite Workings (Untersuchungen an Förderketten für Braunkohlentagebaue), A. Pomp. Braunkohle, vol. 26, no. 1, Apr. 2, 1927, pp. 1037-1047, 17 figs. Discusses desirable properties of materials for such chains; gives results of tests and experiments on mild steel showing effect of overheating, recrystallization, temperature deformations, age, etc., upon mechanical properties and metallographic structure; speaks of regeneration by reheating and its effect upon mechanical properties.

DEFORMATION. Conditions Governing Yield Lines Indicating Commencement of Permanent Deformation (Conditions d'apparition des lignes de cession marquant le debut des déformations permanentes), J. Seigle. Génie Civil, vol. 90, no. 24, June 11, 1927, pp. 576-578, 18 figs. Study supplementary to those by author, published in same journal in 1926; deals with tensile stress of bars with enlarged section; effect of cold working; yield lines and deflection due to bending; yield lines due to torsion; hardened soft-steel bars; etc.

FLAWS. Flaws in the Manufacture of Mild Steel. Their Causes and Methods for Preventing Them (Bei der Verarbeitung von weichem Flussstahl auftretende Fehler, ihre Ursachen und ihre Verhütung), F. Körber. Stahl u. Eisen, vol. 47, no. 28, July 14, 1927, pp. 1157-1166, 29 figs. Speaks of formation of coarse grain structure, on account of overheating or crystallization, also of increase in brittleness due to age, of liquation, blowholes in thin plates, and economy of preventing these defects.

HARDENED AND ANNEALED. Mechanichal Properties of Hardened and Annealed Carbon Steels (Ueber die mechanischen Eigenschaften gehärterter und angelassener Kohlenstaffstahl), Sauerwald and H. Viessen. Centralblatt der Hütten u. Walzwerke, vol. 31, no. 17, Apr. 27, 1927, pp. 207-211. Account of tests, at Technical College of Breslau, on pearlitic and tool steels (0.8 to 1.45 per cent carbon) showing elastic strength to vary directly and hardness inversely with temperature and duration of annealing process.

HIGH TEMPERATURE PLANTS. The Design of Plant for High-Temperature Service, R. W. Bailey. Engineering, vol. 124, no. 3208, July 8, 1927, pp. 44-46, 7 figs. Points out that there is extremely little information relating to stresses and temperatures at which plastic distortion will be ruling factor; but author indicates that there is room for more optimism in proceeding to higher temperatures than is generally thought to be the case. Paper read before Inst. Mech. Engrs.

MOLTEN, GAS CONTENT OF. New Process for Determination of Gas Content of Molten Metal (Ein neues Verfahren zur Bestimmung des Gasgehaltes von flüssigen Metallschmelzen), A. Wüster and E. Piwowarsky. Stahl u. Eisen, vol. 47, no. 17, Apr. 28, 1927, pp. 698-702, 5 figs. Method of determining gas contained in known volume of molten iron or steel intended primarily for work on small laboratory scale; method consists in sucking molten metal into previously evacuated chill mold, gases evolved during solidification being collected in evacuated glass apparatus connected with mold. See also review of above article in Metallurgist (Supp. to Engineer), June 24, 1927, p. 87.

REPEATED STRESSES, EFFECT OF. Changes in Microstructure of Structural Steels Caused by Repeated Stresses (Die Veränderung im Kleingefüge verschiedener Baustähle durch Wechselbeanspruchung), W. Herold. V. D. I. Zeit., vol. 71, no. 29, July 16, 1927, pp. 1029-1032, 24 figs. Microphotographs of structure of manganese and chrome-nickel steels before and after stressing, some of them showing crystallization, fatigue cracks, etc.; results of tests discussed.

SCALING. The Influence of Atmosphere and Temperature Upon the Scaling of Steel, C. G. Marson, J. W. Cobb and H. T. Angus. Forging-Stamping-Heat Treating, vol. 13, nos. 4 and 5, Apr. and June 1927, pp. 118-123 and 178-180, 1 fig. Scaling effect of air, water vapor, CO and CO_2, determined by series of experiments.

STAINLESS. Stainless Steel, T. G. Burton. S. African Instn. Engrs.—Jl., vol. 25, no. 11, June 1927, pp. 218-228 and (discussion) 228-233, 6 figs. Deals with mechanical and physical properties, and uses.

STEEL CASTINGS

FLAWS, PREVENTION OF. Prevent Flaws in Steel Castings, J. L. Gibney. Foundry, vol. 55, no. 13, July 1, 1927, pp. 526-529, 19 figs. Cavities may exist in steel castings and never appear until casting fails under severe load or test; in writer's opinion introduction of nails affords most satisfactory solution to problem; reports from many sources indicate that chill nails are used extensively both in green-sand and dry-sand molds.

LARGE. The Manufacture of a Large Steel Casting, F. A. Melmoth. Foundry Trade Jl., vol. 36, nos. 568 and 569, July 7 and 14, 1927, pp. 19-22 and 45-48, 18 figs. Outlines complete history of production of large steel casting taking case of cast-steel propeller-shaft bracket; sand preparation; making of mold; annealing; welding.

REPLACEMENT CAUSES. Utilizing The Master Mechanic's Knowledge of Replacement Causes. Research Group News, vol. 4, no. 2, July 15, 1927, pp. 132-137, 14 figs. Author seeks to stimulate interest of industrial executives in details of maintenance expense through information obtained at first hand from those whose duty is to make replacements.

STEEL, HEAT TREATMENT OF

ALLOYS, EFFECT OF. Effect of Alloys Upon the Structure and Physical Properties of Steel, H. M. Boylston. Fuels & Furnaces, vol. 5, no. 7, July 1927, pp. 841-848, 18 figs. Discussion of effect of alloys on critical points and variation in heat treatment due to difference in composition; suitability of various alloy steels for different applications.

ANNEALING. Annealing of Hardened Steels (Die Vorgänge beim Anlassen gehärteter Stähle), L. Traeger. V. D. I. Zeit., vol. 71, no. 25, June 18, 1927, pp. 891-894, 7 figs. Measurement of longitudinal changes in hardened carbon steels with annealing; it is shown that process of annealing takes place in 3 separate stages which begin at about 100, 235, and 275 deg.; observed phenomena show that changes take place in steel which are explained; knowledge of these phenomena provide suggestions for heat treatment of steel.

ELECTRIC. Automatic Heat Treatment of Springs in Electric Furnace, O. C. Trautman. Fuels & Furnaces, vol. 5, no. 7, July 1927, pp. 895-897, 3 figs. Heat treatment of automobile valve springs and miscellaneous springs in electric roller-hearth furnace entirely automatic from time material is loaded into trays until it is discharged from quenching tank conveyor.

ELECTRIC. Electric Heat Treating Installation. Forging—Stamping—Heat Treating, vol. 13, no. 6, June 1927, p. 241. In plant burning natural gas substitution of electricity affected reduction both in cost of operation and in refections; temperature control more positive.

OIL-WELL SUCKER RODS. Heat Treated Sucker Rods Reduce Failure by Breakage, W. J. Crook. Nat. Petroleum News, vol. 19, no. 26, June 29, 1927, pp. 85, 87, 88, 91 and 93. Conditions under which sucker rods of optimum quality and usefulness must be produced; nature of rod failures; fatigue limit and ultimate strength methods of increasing strength; metallurgical design of sucker rods. See also Oil & Gas Jl., vol. 26, no. 6, June 30, 1927, pp. 79 and 148, 4 figs.

QUENCHING. A Practical Course in the Elements of Physical Metallurgy. Forging—Stamping—Heat Treating, vol. 13, no. 6, June 1927, pp. 237-240. Quenching; classification of quenching mediums; pyrometers.

TERMINOLOGY. Joint Technical Society Definitions of Heat Treatment Terms. Research Group News, vol. 4, no. 2, July 1927, pp. 130-132, 2 figs. Gives complete definitions adopted by Am. Soc. Testing Matls.

TOOLS AND DIES. Importance of Heat-Treatment in Tool Building, F. Waldo. Am. Mach., vol. 67, no. 4, July 28, 1927, pp. 151-154, 11 figs. Heat treatment of tools and dies at plant of Century Electric Co., St. Louis, Mo., is considered one of major functions of toolroom; in laying out heat-treating room, three factors were considered: furnace equipment, method of recording heats accurately, and operating facilities.

STEEL, HIGH SPEED

COBALT. Properties of High-Speed Cobalt Steel (Eigenschaften kobaltlegierter Schnellarbeitsstähle), W. Oertel. Zeit. des Oesterr. Ingenieur- u. Architekten-Vereins, vol. 79, no. 17-18, Apr. 29, 1927, pp. 158-160. Tests of three sorts of steel with cobalt content, zero, 1.03 and 3.53 per cent, showed hard-

ness and cutting power varying directly with cobalt content and hardening temperature; cost analysis shows that use of 5 per cent or 8 per cent cobalt steel in high-speed lathes will result in considerable economy.

STEEL MANUFACTURE

BASIC OPEN-HEARTH. Making Basic Open-Hearth Steel, C. W. Veach. Blast Furnace & Steel Plant, vol. 15, no. 7, July 1927, pp. 323-325. Discusses several features such as furnace construction, operation, charging and heat control.

MUNITIONS. Making Steel for Munitions, R. R. Nix. Iron Age, vol. 120, no. 2, July 14, 1927, pp. 67-70. Coöperation between War and Navy departments and industry; progress in metallurgy hastened by military demands; gun barrels for street lighting; quality steel for naval ships; making gun forgings; discovery of alloys and their uses; cold working of steel; molybdenum in steel.

SWEDISH WIRE RODS. The Manufacture of Swedish Wire Rods, N. Danielsen. Wire, vol. 2, no. 7, July 1927, pp. 223-224. Entire manufacture of Swedish high-quality steel is based on charcoal pig iron; whether pig iron is converted into steel by electric or by Siemens Martin acid process only small units are used; wire rods are formed out of ingot by rolling billets, which are then reheated and turned out to wire rods.

STEEL WORKS

TIMKEN ROLLER BEARING CO. New Steel Plant of the Timken Company. Blast Furnace & Steel Plant, vol. 15, no. 7, July 1927, pp. 317-318, 4 figs. Steel melted in both electric and open-hearth furnaces; charging machine and ladle crane of improved design; plant arranged for economical operation.

STELLITE

CHARACTERISTICS. Stellite, J. J. Bruton. West. Machy. World, vol. 18, no. 6, June 1927, pp. 268-269 and 281, 3 figs. What is probably most valuable and important characteristic of stellite is fact that it is possible to melt metal by means of oxy-acetylene torch, fuse it to all grades of steel and practically all of cast iron, and have without any heat treatment resultant surface which still retains all of desirable properties of alloy.

STRUCTURAL STEEL

TORSIONAL FATIGUE. Torsional Fatigue Limits, T. H. Burnham. Engineering, vol. 124, no. 3208, July 8, 1927, pp. 33-34, 2 figs. Review of paper by Föppl published in V. D. I. Zeit., on Behavior of Structural Steel Under Repeated Torsional Stress.

YIELD POINT. Progress Report of Research Committee on Yield Point of Structural Steel. Am. Soc. Testing Matls.—Advance paper, no. 25, for mtg. June 20-24, 1927, 2 pp. Three fundamental parts of problem before committee are: (1) significance to engineer of yield point when determined accurately; (2) range in yield point of structural steel (that is, low-carbon, medium-carbon, silicon, and nickel steel) when furnished under specifications; and (3) testing procedure which will insure sufficiently accurate determination of yield point at minimum expense.

TANTALUM

PROPERTIES. Tantalum—A Rival for Platinum. Eng. & Min. Jl., vol. 123, no. 22, May 28, 1927, p. 888. Working properties of tantalum are such that it can be worked cold, drawn, hammered, machined, polished, hardened, rolled and punched; pure metal is rather easily worked; it is highly resistant to chemical corrosion.

TESTS AND TESTING

METHODS. Report of Committee E-1 on Methods of Testing. Am. Soc. Testing Matls.—Advance paper, no. 3, for mtg. June 20-24, 1927, 13 pp., 2 figs. Reports of subcommittees on mechanical testing; impact testing; volatility; plasticity consistency, etc.; determination of water; size and shape; methods for density; chemical composition.

THERMOCOUPLES

METALS AND ALLOYS FOR. Metals and Alloys for Thermocouples for the Measurement of High Temperature (Metalle und Legierungen für Thermoelemente zur Messung hoher Temperaturen) W. Rohn. Zeit. für Metallkunde, vol. 19, no. 4, Apr. 1927, pp. 138-144, 4 figs. Deals with thermocouples of platinum and platinum-rhodium, thermoelectric alloys of other than same metals; oxidation resistance of nickel and chrome-nickel alloys of varying chrome content; interchangeability of thermocouples; protective tubes for thermocouples, especially for protection against molten copper.

TEMPERATURE MEASUREMENT WITH. Temperature Measurement with Thermocouples (Verfahren der Temperaturmessung mit Thermoelementen), Zeit. für Metallkunde, vol. 19, no. 4, Apr. 1927, pp. 144-148, 11 figs. Methods for direct and indirect measurement of electromotive force of thermocouples, their sources of error and accuracy obtainable.

TUNGSTEN

GRAIN SIZE AND TEMPERING. X-Ray Investigation of the Grain Size and of Tempering in Tungsten Wire X (Der röntgenographische Nachweis von Kornwachstum und Vergütung in Wolframdrähten mittels des Debye-Scherrer-Verfahrens), K. Becker. Zeit. für Physik, vol. 32, no. 2-3, Apr. 1, 1927, pp. 226-245, 13 figs. Modification of Debye-Scherrer technique suitable for investigation of grain size and of effect of tempering in metallic wires; variation in grain size and effect of tempering at various temperatures have been examined by this method for ordinary and for single-crystal tungsten wires after mechanical deformation by stretching.

METALLURGY AND USES. The Metallurgy and Uses of Tungsten, G. M. Dyson. Chem. Age, vol. 16. no. 410, May 7, 1927, pp. 33-35, 3 figs. Extraction of metal; reduction; properties.

VANADIUM

DETERMINATION OF. The Determination of Vanadium in Metallurgical Products, W. Singleton. Chem. Age, vol. 17, no. 418, July 2, 1927, pp. 1-5. Methods for determination which are particularly applicable to ores, ferrovanadium, and steel; existing meth-

ods for determination of vanadium and its separation from other metals; attention is directed to electrometric methods.

PROPERTIES. Vanadium, F. W. Marden and M. N. Rich. Indus. & Eng. Chem., vol. 19, no. 7, July 1927, pp. 786-788, 1 fig. Vanadium has been prepared; contrary to previous statements in literature, this metal is not like arsenic or bismuth; it is not brittle but may be cold-worked into wire or other forms; physical properties, such as specific gravity, electrical conductivity, etc., have been determined; in properties vanadium resembles tantalum.

WATER MAINS

CORROSION. Corrosion in a Water Supply System and Methods of Protection, E. B. Stewart. Am. Water Wks. Assn.—Jl., vol. 17, no. 5, May 1927, pp. 557-568. Theory of corrosion; soil corrosion and preventive measures; electrolysis; remedial measures applicable to structures; coöperative treatment of electrolysis problem.

CORROSION. Fighting Corrosion in the Wiesbaden and Remache Water Mains (Bekämpfung der Korrosion in den Wiesbadener und den Remschneider Wasserleitungen), C. Bücher and A. Schulte. Gas u. Wasserfach, vol. 70, nos. 7, 8, 9, 10, 11 and 12, Feb. 12, 19, 26, Mar. 5, 12, 19, pp. 141-144, 171-174, 194-199, 219-223, 241-252 and 271-274, 54 figs. Scientific explanation of corrosion phenomena; tests and experiences with corrosion in water mains; means of preventing corrosion; Remscheid plant for protection of mains.

WELDING

AUTOMOBILE BODY PANELS. Body Panels Welded from Small Punchings Economically. Automotive Mfr., vol. 49, no. 4, July 1927, p. 8. Pierce-Arrow engineer describes advantages of that company's method of avoiding use of deep drawings, stretched material, expensive tools and dies.

CAST ALUMINUM. Welding Cast Aluminum. Mech. World, vol. 81, no. 2107, May 20, 1927, pp. 357-358. Describes operations and makes recommendations for welding.

FUSION. Trend of Fusion Welding Research, J. R. Dawson. Am. Welding Soc.—Jl., vol. 6, no. 6, June 1927, pp. 45-46. Importance of fusion welding has increased in proportion to its ability to replace other types of joints; it has great advantage in that with a small amount of relatively inexpensive apparatus, perfectly tight joints of high strength are produced and it is successfully applied to all metals and alloys for each of which welding rods of special composition have been devised.

MANAGEMENT OF. Preparing, Supervising and Testing of Welding Work (Die Vorbereitung, Ueberwachung und Prüfung der Schweissarbeiten bei der Schmelzschweissung), D. Bardtke. Maschinenbau, vol. 6, no. 11, June 2, 1927, pp. 541-548, 25 figs. Modern methods of welding and testing of welds and role of engineer in managing work.

RAILWAY TIES. D. & H. Tests New Scrap-Rail Welded Cross-Tie. Ry. Eng. & Maintenance, vol. 23, no. 6, June 1927, pp. 253-254, 3 figs. Utilizes track materials released from original service for further use in new form.

RESEARCH. Developments and Research in Welding, D. H. Deyoe. Am. Welding Soc.—Jl., vol. 6, no. 4, Apr. 1927, pp. 48-58, 12 figs. New Magnetic clutch type automatic welder and control; travel carriage for automatic welders; multiple-arc automatic welder; straight seam welders for range boilers, small and large tanks and pipe; control of magnetic fields in arc when welding; pneumatic backing bar; circular seam welders; atomic hydrogen welding and shrouded arc welding; electrodes; metallurgical research; copper-tungsten electrode for spot welders; all-steel arc-welded railroad tie.

RESEARCH. Welding Research Activities of the Newport News Shipbuilding & Dry Dock Company During 1926, J. W. Owens. Am. Welding Soc.—Jl., vol. 6, no. 4, Apr. 1927, pp. 59-73, 9 figs. Deals with research in resistance, gas, metallic arc and thermit welding; corrosion tests.

RESEARCH. Welding Research, C. A. McCune. Am. Welding Soc.—Jl., vol. 6, no. 6, June 1927, pp. 39-45, 8 figs. Welding research as carried on in laboratory of Am. Chain Co. occupies attention of five distinct types of people in which are included the engineer, welder, metallurgist, chemist and physicist.

RODS. Shop Tests for Welding Rods, P. L. Roberts. Welding Engr., vol. 12, no. 7, July 1927, pp. 47-48. A simple and practical system for keeping record of welding qualities of every type of filler material used.

STEEL PIPE. Welding of Steel Pipes (Schweissung von Stahlrohren), Schlee. Gas u. Wasserfach, vol. 70, no. 22, May 28, 1927, pp. 501-508, 23 figs. General principles of welding in their application to pipe welding, particularly gas pipes; cost data show welded joints made at about half price of lead joints; protection of pipe joints.

STRUCTURAL STEEL. Application of Welding to a Steel Structure, J. H. Edwards. Am. Iron & Steel Inst.—advance paper, for mtg., May 20, 1927, 37 pp., 22 figs. Deals with electric resistance method; and fusion welding, either gas or electric.

THERMIT. Research Activities of the Metal and Thermit Corp., J. H. Deppeler. Am. Welding Soc.—Jl., vol. 6, no. 4, Apr. 1927, pp. 43-46. Research activities of this corporation are carried on at its Jersey City plant; work includes welding research which has to do with development of iron thermits that will produce steel of proper physical characteristics.

THERMIT. Thermit Welding Practice Improved. Welding Engr., vol. 12, no. 5, May 1927, pp. 32-33, 3 figs. New Methods of design and procedure reduce amount of materials used and improve quality of weld.

THERMIT. Thermit Welding. Am. Welding Soc.—Jl., vol. 6, no. 6, June 1927, 54 pp., 60 figs. Instructions for the making of thermit welds, compiled by Educational Committee of Am. Welding Soc. as a source of reference for welders or operators using thermit process; kinds of thermit, making a thermit weld, welding locomotive frames, crankshaft repairs, steel-mill repairs, welding rails, marine repairs, welding pipe with thermit.

WATER GAS. Construction of Steel Tanks by Water Gas Welding (Behälterbau aus Eisenblech mittels Wassergasschweissung), E. Pohl. Centralblatt der Hütten u. Walzwerke, vol. 31, no. 4, Jan. 26, 1927, pp. 35-36, 4 figs. Process requiring water gas torches on inner and outer sides of plate, suited for welding of thickest plates and guaranteeing weld strength 90 per cent of plate strength.

WIRE. Report to the Welding Wire Specification Committee, C. A. McCune. Am. Welding Soc.—Jl., vol. 6, no. 5, May 1927, pp. 44-50, 6 figs. Account of meeting of reorganized Welding Wire Specifications Committee called to determine in what manner, if any, present specifications can be made more rigid so as to further guarantee that welding wire purchased according to these specifications will be satisfactory.

X-RAY APPLICATION TO. Application of X-rays to Welding Practice (Anwendung der Röntgenstrahlen in der Schweisstechnik), C. Kaniner and A. Herr. V. D. I. Zeit., vol. 71, no. 17, Apr. 1927, pp. 571-576, 45 figs. Investigations of materials and welds; discussion of X-ray equipment; evaluation of results.

WELDS

FATIGUE OF. Fatigue of Welds, R. R. Moore. Am. Welding Soc.—Jl., vol. 6, no. 4, Apr. 1927, pp. 11-32, 21 figs. Results of tests relating to welding metal thicknesses not greater than 3/16 in. and usually not over 1/16 in. such as in case of steel tube fuselage with welded joints; results are given for gas and arc welds and for atomic hydrogen process; cast steel tests; although tensile efficiency was better than 75 per cent, fatigue strength was as low as 13 and never higher than 35 per cent of tensile strength of weld; poor fusion has drastic effect upon resistance of weld to repeated stresses.

RED SHORTNESS. The Red-Shortness of Weld Metal, A. H. Goodger. Welding Jl., vol. 24, no. 285, June 1927, pp. 166-169, 8 figs. Trouble is usually due to presence of certain impurities such as sulphur or oxygen, which may give rise to brittle films between grains; fractures are usually intergranular.

WIRE

COPPER. Report of Committee B-1 on Copper Wire. Am. Soc. Testing Matls.—advance paper, no 17, for mtg., June 20-24, 4 pp. Tentative revisions of existing standards; tentative specifications revised and continued as tentative.

HARD-DRAWN. The Effect of Gradual Annealing on Specific Cold Resistance of Hard-Drawn Wires (Die Einwirkung stufenweisen Ausglühens auf den spezifischen Kaltwiderstand hartgezogener Drähte), W. Rohn. Zeit. für Metallkunde, vol. 19, no. 5, May 1927, pp. 196-199, 3 figs. With aluminum and copper, specific electric resistance is lower with annealed than with hard-drawn material; with nickel and iron, electric cold resistance is not affected or annealing of hard-drawn material; with nickel-copper alloys 45:55, and with chrome-iron and nickel alloys 11:22:62, cold resistance of hard-drawn wires decreases considerably with annealing, and temperature coefficient decreases somewhat; mechanism of resistance changes due to annealing seems to be at least partially dependent on recrystallization.

STEEL, MANUFACTURE. The Manufacture of Wire and Wire Ropes, J. E. Thompson. Mech. World, vol. 81, nos. 2093 and 2094, Feb. 11 and 18, 1927, pp. 99-100 and 120-121, 8 figs. Two principal processes which are used in manufacture of steel for rope wire are: (1) basic Siemens-Martin process; (2) acid Siemens-Martin process; latter may be further subdivided into: (a) acid, (b) special acid, (c) Swedish acid; annealing; cleaning; wire-drawing. Feb. 18: Testing.

WOVEN NETTING. Woven Wire Netting, M. A. Hall. Wire, vol. 2, no. 7, July 1927, pp. 239-242 and 248, 3 figs. Details of manufacturing process.

WIRE DRAWING

STEEL. The Relation of Steel Quality to the Drawing of Steel Wire, E. A. Atkins. Wire, vol. 2, no. 7, July 1927, pp. 226-229, and 252, 22 figs. Segregated steel; surface defects and hollowness; effect of non-metallic inclusions; cause of wire "running out" or not sizing correctly; nature of hard inclusions.

STEEL. The Drawing of Steel Wire and Its Relation to Qualities of Steel, E. A. Atkins. Iron & Coal Trades Rev., vol. 114, no. 2088, May 6, 1927, pp. 752-739, 5 figs. Flow of metal in drawing; segregated steel; effect of non-metallic inclusions; cause of wire "running out" or not sizing correctly; nature of hard inclusions; making of clean steel suitable for wire-drawing; dissolved oxide in steel; effect of accidental constituents in steel; effect of varying carbon contents and temperature on annealing for subsequent cold work; cementite in mild-steel wire; effect of varying analyses on tempering. See also Engineering, vol. 123, no. 3200, May 13, 1927, pp. 591-594. Paper read before Iron & Steel Inst.

WIRE ROPE

PROPERTIES. Some Investigations on the Properties of Rope Wire, A. T. Adam. Wire, vol. 2, no. 5, May 1927, pp. 151-153, 4 figs. Notes on overdrawing, fatigue limit, internal stress and heating; reverse bend tests on wire patented in various sizes and drawn to 0.071 in. diameter.

WROUGHT IRON

STANDARDS. Report of Committee A-2 on Wrought Iron. Am. Soc. for Testing Matls.—advance paper, no. 9, for mtg., June 20-24, 1927, 3 pp. Recommendations affecting standards and tentative standards.

X-RAYS

METAL EXAMINATION. Investigation of Metallic Layers by X-rays (Eine Methode zur Untersuchung der einzelnen Schichten eines Werkstoffes), K. Becker. Zeit. für Physik, vol. 42, no. 2-3, Apr. 1, 1927, pp. 222-225, 5 figs. X-ray reflection method which is particularly adapted for investigation of change in crystal structure produced in wires by mechanical deformation.

News of the Society

THE EXPOSITION

THE great Detroit Convention Hall has been reserved for the Ninth Annual National Steel and Machine Tool Exposition, held under the auspices of the American Society for Steel Treating.

Over 93,000 square feet have been reserved by exhibitors, and practically 75% of the equipment will be shown in operation.

Eighty thousand visited the Exposition in Chicago last year, while 100,000 are expected at Detroit. The Exposition will be *larger* than that held in Chicago last year.

This great Exposition represents a complete cycle in the metal working and the metal treating industry. (1) It depicts the steel from the raw material to the form in which it is used, as shown by the steel manufacturers. (2) The machinery section where manufacturers will have their equipment in operation. (3) After the steel is fabricated, it will then be shown in the heat treating department, and all of the most important and up-to-date manufacturers of heat treating equipment and materials will have their products on display and in operation. (4) From the heat treating department the steel then goes to the inspection department, and inspection tools and equipment will be shown by numerous manufacturers.

The Welding and Cutting Exposition held under the auspices of the American Welding Society and in co-operation with the National Steel and Machine Tool Exposition in Detroit the week of September 19 will be the largest exhibit of its kind ever held. A special section of Convention Hall of over 15,000 square feet has been set aside for the welding exhibit. Consequently all of the exhibits will be grouped together and the thousands in attendance will have the opportunity to observe the latest and best equipment and developments in this line. The two previous exhibitions of the American Welding Society at Boston and at Buffalo occupied less than one-half the space that will be devoted to welding at the Detroit show.

Thus we have the complete cycle, from the raw material to the finished product. No other exposition is so educational, so complete; no other exposition offers such an exceptional opportunity to see all the related lines in the metal working and metal treating industry.

REDUCED RAILROAD RATES

Members of the A. S. S. T., A. W. S., S. A. E., and I. of M., have been granted reduced fare rates for the Detroit Convention. The railroads have agreed to sell round trip tickets at fare and one-half on the identification certificate plan.

The identification certificates have been mailed to the members of these societies directly from each of the society headquarters.

Please note that tickets purchased with identification certificates will not be accepted on extra fare trains. Tickets may be purchased going from Sep-

tember 15th to 21st (incl.) with final return limit to original starting point, not later than midnight, September 29th.

Any member having a round trip ticket to Detroit reading via Buffalo or Cleveland may, if he so chooses, use the boats of the D. & C. line. The D. & C. Navigation Company will accept, on their steamers for transportation, going or returning, that portion of your railroad ticket calling for transportation from either Buffalo or Cleveland to Detroit.

HOTEL HEADQUARTERS

The Hotel Statler will be headquarters for the American Society for Steel Treating and the Society of Automotive Engineers while the Book-Cadillac Hotel will be headquarters for the American Welding Society and Institute of Metals.

Registration of members in attendance at the convention and exposition will be as follows:

S. A. E. registration—Hotel Statler.
A. W. S. registration—Book-Cadillac Hotel.
I. of M. registration—Book-Cadillac Hotel.
A. S. S. T. registration (ladies only)—Hotel Statler.
A. S. S. T. registration of members, guests and exhibitors—Convention Hall.

A. S. S. T. members will be asked to present their membership cards in order to facilitate registration.

Guests desiring to participate in technical and social activities of the A. S. S. T. may do so upon registration and payment of a $3.00 fee. No registration fee is required of members of the American Welding Society, Society of Automotive Engineers, American Society for Steel Treating, Institute of Metals, or Exhibitors.

NINTH ANNUAL CONVENTION

Technical Program

The technical sessions of the Annual Convention of the American Society for Steel Treating have for years stood out in great prominence as of splendid caliber and presenting the latest advances in research and investigation in the metallurgy of metals. The papers scheduled for presentation at the Detroit Convention are no exception to this precedence, as a most comprehensive group of papers have been selected and scheduled for presentation during the week of September 19. Recognized thinking men of the industry will present new and worth while ideas both in the form of technical papers and in discussion of technical papers presented. All sessions will be held in the Ball Room of the Hotel Statler, except the session Wednesday afternoon which will be held at the Book-Cadillac Hotel.

CAMPBELL MEMORIAL LECTURE

The Edward DeMille Campbell Memorial Lecture will be presented by Dr. Zay Jeffries, of Cleveland, on Wednesday morning, September 21, immediately following the close of the annual meeting of the American Society for Steel Treating. Dr. Jeffries, recognized as the world's leading theoretical metallurgist, will present a lecture of outstanding importance. Prof. A. H. White, of the University of Michigan, will preside as chairman of the memorial session.

TECHNICAL PAPERS PROGRAM, NINTH ANNUAL CONVENTION AMERICAN SOCIETY FOR STEEL TREATING DETROIT, SEPTEMBER 19-23, 1927

MONDAY, SEPTEMBER 19

Morning Session

Meeting in Ball Room, Hotel Statler,
J. L. McCloud, Chairman,
E. J. Hergenroether, Vice-Chairman.

10:00—10:35 A. M.—*Deep Etch Test for Iron and Steel*—H. G. Keshian, Chase Metal Works, Waterbury, Conn.

10:35—11:10 A. M.—*Aircraft Metallurgy*—H. C. Knerr, Consulting Metallurgist, Philadelphia.

11:10—11:30 A. M.—*Furnace Development in Heat Treating and Forging*—W. M. Hepburn, Surface Combustion Company, Bronx, N. Y.

11:30—12:00 A. M.—*Hardening by Re-Heating After Cold Working*—M. A. Grossmann and C. C. Snyder, Central Alloy Steel Corp., Canton, Ohio.

Patenting of Steel—J. S. G. Primrose, Metallurgical and Testing Engineer, Manchester, England, (By Title)

Afternoon Session

Meeting in Ball Room, Hotel Statler
H. F. Moore, Chairman
R. R. Moore, Vice-Chairman

2:00—2:20 P. M.—*A Critical Study of the Bend Test as Applied to Iron and Steel*—A. B. Kinzel, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.

2:20—2:50 P. M.—*Gas Carburization of Steel*—R. G. Guthrie and Dr. O. J. Wozasek, Peoples Gas Light and Coke Company, Chicago.

2:50—3:20 P. M.—*Carburizing Iron by Mixtures of Hydrogen and Methane*—W. P. Sykes, General Electric Company, Cleveland.

3:20—3:45 P. M.—*Fatigue Tests of Carburized Steel*—H. F. Moore and N. J. Alleman, University of Illinois, Urbana, Ill.

3:45—4:10 P. M.—*Studies of Normal and Abnormal Carburizing Steels*—O. E. Harder, L. J. Weber and T. E. Jerabek, University of Minnesota, Minneapolis.

TUESDAY, SEPTEMBER 20

Morning Session

Meeting in Ball Room, Hotel Statler
Radclyffe Furness, Chairman
Martin Schmid, Vice-Chairman

10:00—10:30 A. M.—*Steel Melting Practice for Large Ingots Heavy and Light High Grade Castings*—W. H. White, Duquesne Steel Foundry Company, Coraopolis, Pa.

10:30—11:00 A. M.—*The Melting or Molten Stage of Steel Manufacture with Particular Reference to the Deoxidizing, Refining and Contamination Phases*—G. A. Dornin, The Gathmann Engineering Company, Baltimore.

11:00—11:30 A. M.—*Armco Ingot Iron*—R. L. Kenyon, American Rolling Mill Company, Middletown, Ohio.

11:30—12:00 A. M.—*Segregation of Dissolved Elements and its Influence upon Carbon Distribution in Steel*—E. G. Mahin and H. J. Dillon, University of Notre Dame, Notre Dame, Ind.

Afternoon Session

Meeting in Ball Room, Hotel Statler
J. A. Mathews, Chairman
B. F. Shepherd, Vice-Chairman

2:00—2:20 P. M.—*The Development of High Speed Steel Hacksaws or Cutting off Saws*—H. B. Allen, Henry Disston & Sons, Inc., Philadelphia.

2:20—2:50 P. M.—*A High Temperature Quenching Treatment Applied to Cold Heading Ball Dies of Plain Carbon Tool Steel*—F. L. Wright, Atlas Ball Co., Philadelphia.

2:50—3:20 P. M.—*Evaluating Quality in Heat Treated High Speed Steel by Means of the Milling Cutter*—J. B. Mudge and F. E. Cooney, Western Electric Company, Chicago.

3:20—3:45 P. M.—*On the Constitution and Properties of Hardened Steel*—W. P. Sykes and Zay Jeffries, General Electric Company, Cleveland.

3:45—4:15 P. M.—*Testing Automobile Body Sheet Steel*—Joseph Winlock and George L. Kelley, Edward G. Budd Manufacturing Co., Philadelphia.

WEDNESDAY, SEPTEMBER 21

Morning Session

9:30 A. M.—ANNUAL MEETING OF THE AMERICAN SOCIETY FOR STEEL TREATING—Ball Room, Hotel Statler.
Chairman—J. Fletcher Harper

10:30 A. M.—E. D. Campbell Memorial Lecture by Dr. Zay Jeffries.
Prof. A. H. White, Chairman

Afternoon Session

2:00 P. M.—JOINT MEETING WITH THE I. OF M. D., A. I. M. E.—Hotel Book-Cadillac.

THURSDAY, SEPTEMBER 22

Morning Session

Meeting in Ball Room, Hotel Statler
Frank P. Gilligan, Chairman
Frances Hurd Clark, Vice-Chairman

10:00—10:30 A. M.—*On the Significance of the Proportional Limit of Steel at Elevated Temperatures*—F. B. Foley, The Midvale Company, Nicetown, Philadelphia.

10:30—11:00 A. M.—*Recent Experiments Relating to the Wear of Plug Gages*—H. J. French and H. K. Herschman, Bureau of Standards, Washington, D. C.

11:00—11:30 A. M.—*What Happens When High Speed Steel is Quenched*—B. H. DeLong and F. R. Palmer, The Carpenter Steel Company, Reading, Pa.

11:30—12:00 A. M.—*On the Double Carbide of High Speed Steel*—Dr. Arne Westgren and Gosta Phragmen, Metallografiska Institutet, Stockholm, Sweden. (Paper to be read by Dr. Zay Jeffries).

On a New Method of Quenching Steel in a High Temperature Bath—Dr. Kotaro Honda and Kanzi Tamaru, Imperial University, Sendai, Japan. (By title)

Afternoon Session

Meeting in Ball Room, Hotel Statler
H. M. Boylston, Chairman
H. J. French, Vice-Chairman

2:00—2:30 P. M.—*Dilatometric Analysis of Steel and Some Results of*

Dilatometric Heat-Treatment—R. W. Woodward and Stanley P. Rockwell, The S. P. Rockwell Company, Hartford, Conn.

2:30—3:00 P. M.—*The Physical Properties of Several Chromium-Aluminum and Chromium-Nickel-Aluminum Steels*—V. O. Homerberg and I. N. Zavarine, Massachusetts Institute of Technology, Cambridge, Mass.

3:00—3:30 P. M.—*The Economic Value of Nickel and Chromium in Gray Iron Castings*—D. M. Houston, The International Nickel Company, New York City.

3:30—4:00 P. M.—*Expansion Characteristics of Low Expansion Nickel Steels*—Howard Scott, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

On the Determination of the Heterogeneous Field In the Iron-Nickel System—Dr. Kotaro Honda and Sansaku Muira, Imperial University, Sendai, Japan (By title)

Heat Treatment of Two Ball Bearing Steels—Bengt Kjerrman, S. K. F, Gothenberg, Sweden. (By title)

FRIDAY, SEPTEMBER 23

Morning Session

Meeting in Ball Room, Hotel Statler
R. M. Bird, Chairman
J. A. Succop, Vice-Chairman

10:00—10:30 A. M.—*Design from the Heat Treating Standpoint*—G. M. Eaton, Molybdenum Corporation of America, Pittsburgh.

10:30—11:00 A. M.—*Forging Machine Die Design for Deep Piercing*—E. R. Frost, National Machinery Company, Tiffin, Ohio.

11:00—11:30 A. M.—*High Temperature Treatments of Castings and Forgings as Evidenced by Core Drill Tests from Heavy Sections*—W. J. Merten, Westinghouse Electric & Manufacturing Co., East Pittsburgh.

11:30—12:00 A. M.—*Locomotive Forging Steels*—O. V. Greene, Reading Company, Reading, Pa.

Afternoon Session

Meeting in Ball Room, Hotel Statler
W. H. Phillips, Chairman
H. M. German, Vice-Chairman

2:00—2:30 P. M.—*Relationships Between Rockwell, Brinell and Scleroscope Numbers*—R. R. Moore, Wright Field, Dayton, Ohio.

2:30—3:00 P. M.—*Machinability of Metals*—Orlan W. Boston, University of Michigan, Ann Arbor, Mich.

3:00—3:30 P. M.—*High-Speed, High-Voltage X-Ray Diffraction Analysis of Metals*—Dr. Ancel St. John, Consulting Physicist, New York City.

3:30—4:00 P. M.—*The Important Properties and Requirements of Some Special Refractories*—H. F. Beecher, Norton Company, Worcester, Mass.

4:00—4:30 P. M.—*Rate of Loading and Time of Application in Brinell Testing*—H. M. German, Universal Steel Company, Bridgeville, Pa.

ANNUAL BANQUET

The annual banquet will be held at the Statler, Thursday evening, September 22, at 6:30. Two honorary memberships will be conferred and two splendid worthwhile speakers will be present. All seats are reserved. Tickets at $5.00 each may be secured either by addressing the society headquarters in Cleveland or at the registration desk in Detroit.

PLANT INSPECTION

Plant inspection has been arranged for Tuesday, Wednesday, Thursday and Friday afternoons. All inspection trips will start from the Bagley Avenue entrance of the Hotel Statler.

The inspection trips, as listed below, are open to all members and guests of the American Society for Steel Treating. However, all members and guests of the other convening societies are privileged to participate in these inspections in case they so desire. Additional plant inspection trips have been arranged by the American Welding Society.

The schedule follows:

TUESDAY, SEPTEMBER 20, 1:30 P. M.

Cadillac Motor Car Company
Dodge Brothers, Inc.
Budd Wheel Company
Detroit Steel Products Company
Ford Motor Company—Dearborn—Engineering Laboratories and Stout Air Plane Corp. 15 minute ride for $5.00.

WEDNESDAY, SEPTEMBER 21, 1:30 P. M.

Lincoln Motor Company
Hudson Motor Car Company
General Motors Research Laboratories
Detroit Seamless Steel Tubes Company
Victor-Peninsular Company

THURSDAY, SEPTEMBER 22, 1:30 P. M.

General Motors Proving Grounds, Milford, Mich. (all day trip starts 9:30).
Chevrolet Forge and Axle Plant
Fisher Body Corp., Press Room.
Ford Motor Company—Fordson—Formerly the River Rouge Plant.
Detroit Copper and Brass Rolling Mills—succeeded by American Brass Co.

FRIDAY, SEPTEMBER 23, 1:30 P. M.

Packard Motor Car Company
Parke-Davis and Company
Michigan Malleable Iron Company
Studebaker Motor Car Company
General Motors Proving Grounds (all day trip starts 9:30).
Detroit-Edison Company's Trenton Channel Plant (all day trip starts 12:00 noon).

PROGRAM—INSTITUTE OF METALS

The Institute of Metals Division of the American Institute of Mining and Metallurgical Engineers will hold their annual fall meeting at Detroit the week of September 19.

Chairman P. D. Merica and his committeemen have arranged a splendid program of technical sessions and there will be one joint session of the Institute of Metals and the American Society for Steel Treating, to be held at Book-Cadillac Hotel on Wednesday afternoon at 2 P. M.

The entertainment for both ladies and men will be in co-operation with the other societies.

The annual Institute dinner will be held at the hotel headquarters—Book-Cadillac, Wednesday evening.

OUTLINE OF PROGRAM—INSTITUTE OF METALS

Hotel Headquarters, Book-Cadillac

Monday, 19th, Registration, Book-Cadillac, and meetings of various committees.
Tuesday morning—Technical Session.
Tuesday afternoon—Plant inspection.
Tuesday evening—Theatre party.

Wednesday afternoon—Joint session with A. S. S. T.
Wednesday evening—Institute dinner, Book-Cadillac Hotel.
Wednesday, 10:00 P. M.—Grand Arabian Ball, Hotel Statler.

Thursday morning—Technical session.
Thursday afternoon—Plant inspection.

S. A. E. PRODUCTION MEETING

The Production Meeting of the S. A. E. will be held in Detroit, with headquarters at Hotel Statler, on Wednesday and Thursday, September 21 and 22. The program for this meeting is under the direction of John Younger of Ohio State University and Eugene Bouton of the Chandler Motor Car Company. The tentative schedule is as follows:

WEDNESDAY, SEPTEMBER 21

Afternoon—Technical session, Hotel Statler.
Afternoon—Inspection trips.
Evening—Technical session, Hotel Statler.

THURSDAY, SEPTEMBER 22

Afternoon—Inspection trips.
Evening—Technical Session, Hotel Statler.

The Society of Automotive Engineers, both men and ladies, will participate in the general entertainment as listed under "Men's" and "Ladies' Entertainment."

DROP FORGERS' ANNUAL DINNER

The Drop Forgers' Supply Association, Charles Harmon, President; Jules Dierckx, Vice-President and Mr. Wurster, Secretary, are making arrangements

to entertain at dinner on Wednesday evening all of the visiting drop forgers in attendance at the exhibit and meetings of the various technical Societies convening in Detroit the week of September 19th.

Complete information relative to this dinner may be obtained from Charles Harmon, at the booth of the National-Chambersburg Company, Booth No. 231, or from Mr. Dierckx, at the booth of the Keller Mechanical Engineering Co., Booth No. 259.

LADIES' ENTERTAINMENT

All ladies attending the Detroit Conventions and exposition will have their entertainment as a single group. This includes the ladies from the four national societies meeting in Detroit the week of September 19th. The registration for ladies of the American Society for Steel Treating and Society of Automotive Engineers will be at Hotel Statler. Registration for ladies of the American Weldng Society and Institute of Metals will be at Book-Cadillac.

The tentative program is as follows:

MONDAY, SEPTEMBER 19

Registration at Statler Hotel.
Luncheon at Statler.
Auto ride about Detroit.
Visit to Exposition.

TUESDAY, SEPTEMBER 20

Shopping tour or bridge party.
Theatre party.

WEDNESDAY, SEPTEMBER 21

Brief auto ride with luncheon at Detroit Yacht Club.
Musicale at the Detroit Yacht Club.
Grand Arabian Ball, Hotel Statler.

THURSDAY, SEPTEMBER 22

Theatre party at Bonstelle Theatre.
Annual Banquet.

MEN'S ENTERTAINMENT

Those who have attended the past eight conventions of the various societies realize that beside a wonderful series of technical sessions and the exposition, a round of entertainments have always been arranged to add relaxation and enjoyment to educational activities.

The Detroit Convention will be no exception to the long established rule.

Theatre Party

The theatre party this year will be held on Tuesday evening. Admission by ticket *only*, secured when you register.

Grand Arabian Ball

One of the high lights of the Convention will be the Grand Arabian Ball in the Ball Room of the Statler on Wednesday evening at 10:00 o'clock. The room will be transformed into a beautiful Arabian scene. Jean Goldkette's Kentucky Colonels will provide the lively tempo.

Watch for special features of this ball and do not fail to attend. It is arranged exclusively in honor of the members of the four national societies and the exhibitors. Admission by ticket only, secured when you register.

Golf Tournament

A committee, composed of J. M. Watson, Detroit, Chairman; A. O. Fulton, Boston, and W. C. Bell, Cleveland, as members, are in charge of the golf tournament, which will be held on one of Detroit's splendid golf courses.

Prizes

The Firth Sterling Steel Co., International Nickel Co., McGill Metal Co., and General Alloys Co. have all donated for prizes a set of stainless clubs, consisting of midiron, mashie, niblick and putter. In addition to the club sets, numerous other prizes will be awarded.

The following rules govern:

1—Any participant may play in the tournament either Tuesday, Wednesday or Thursday, but the first round on the course any of these days constitutes the tournament score.

2—Each participant will be given a handicap by the tournament committee. This will be based on his State handicap card (if he has one); his club handicap or the average of his best 5 scores for 18 holes made this year. In addition he will be required to give the name of his home course, its par and total yardage. No handicap will be given exceeding 30.

3—U. S. G. A. rules to apply, except where qualified by local rules of the Club where the tournament is played.

4—Gross and net prizes to be equally divided, that is, first, second, third, etc., gross; first, second, third, etc., net.

5—The prizes will be listed by the committee in the order of their importance. No player shall be eligible for more than one prize. In case any player wins more than one prize he will be awarded only that one which is highest on the list.

6—While guests may participate in the tournament, no prizes will be awarded, except to members of the four convening societies and exhibitors.

DAILY NEWSPAPER

Again the Daily Metal Trade, published in Cleveland by the Penton Publishing Company, will issue a special edition during four days of the Convention, with 8 pages devoted exclusively to the activities of the Exposition and Convention. This will have a circulation among the hotels and at the Exposition.

THOSE WHO WILL EXHIBIT IN CONVENTION HALL

The following is a complete list as of September 1 of those companies and individuals who will have exhibits in Convention Hall:

Abrasive Company	Bridesburg, Philadelphia
Acme Electric Welder Company	Huntington Park, Cal.
Acme Stamp Company	Detroit
Air Reduction Sales Company	New York City
Ajax Manufacturing Company	Cleveland
Allegheny Steel Company	Brackenridge, Pa.
Allen & Billmyre Company	New York City

Allis-Chalmers Manufacturing Company	Milwaukee
American Brass Company	Waterbury, Conn.
American Car & Foundry Company	New York City
American Electric Fusion Corporation	Chicago
American Gas Association	New York City
American Gas Furnace Company	Elizabeth, N. J.
American Hoist & Derrick Company	St. Paul
American Lanolin Company	Laurence, Mass.
American Machinist	New York City
American Metal Market	New York City
American Metallurgical Corporation	Boston
American Resistor Company	Milwaukee
American Spring & Manufacturing Company	Holly, Mich.
American Stainless Steel Company	Pittsburgh
American Steel & Wire Corporation	Chicago
Ames Company, B. C.	Waltham, Mass.
Ampco Twist Drill Company	Jackson, Mich.
Andresen & Associates, F. C.	Pittsburgh
Armstrong-Blum Manufacturing Company	Chicago
Armstrong Bros. Tool Company	Chicago
Armstrong Cork & Insulation Company	Pittsburgh
Atkins & Company, E. C.	Indianapolis
Atlas Steel Corporation	Dunkirk, N. Y.

B

Barnes-Gibson-Raymond, Inc.	Detroit
Barnes Company Inc., W. O.	Detroit
Bath & Company, John	Worcester, Mass.
Bausch & Lomb Optical Company	Rochester, N. Y.
Bell & Gossett Company	Chicago
Bellevue Industrial Furnace Company	Detroit
Bellis Heat Treating Company	Branford, Conn.
Bethlehem Steel Company, Inc.	Bethlehem, Pa.
Black & Decker	Towson, Md.
Blacker Engineering Company	New York City
Blaich Company, Alfred O.	Detroit
Blakeslee & Company, G. S.	Chicago
Bliss & Laughlin Inc.	Harvey, Ill.
Bourne-Fuller Company	Cleveland.
Botfield Refractories Company	Philadelphia
Boyer Campbell Company	Detroit
Bristol Company	Waterbury, Conn.
Brown Instrument Company	Philadelphia
Brown Lynch Scott Company	Monmouth, Ill.
Brown & Company, D. P.,	Detroit
Brown-McLaren Manufacturing Company	Detroit
Buckeye Twist Drill Company	Alliance, Ohio
Buffalo Forge Company	Buffalo

C

Campbell Company, A. C.	Bridgeport, Conn.
Carbic Manufacturing Company	Duluth
Carroll Machine and Tool Company	Detroit
Carborundum Company	Perth Amboy, N. J.
Carborundum Company	Niagara Falls, N. Y.
Carpenter Steel Company, The	Reading, Pa.
Case Hardening Service Company	Cleveland
Celite Products Company	Los Angeles
Central Alloy Steel Company	Massillon, O.

Central Steel & Wire Company	Chicago
Chambersburg Engineering Company	Chambersburg, Pa.
Chambersburg-National	Tiffin, Ohio
Char Products Company	Indianapolis
Chesterfield Metal Company	Detroit
Chicago Pneumatic Tool Company	Chicago
Chicago Screw Company	Chicago
Chicago Steel Foundry Company	Chicago
Chicago Steel & Wire Company	Chicago
Chrobaltic Tool Company	Detroit
Chisholm-Moore Manufacturing Company	Cleveland
Clark Tructractor Company	Buchanan, Mich.
Cleveland Twist Drill Company	Cleveland
Climax Molybdenum Company	New York City
Clipper Belt Lacer Company	Grand Rapids, Mich.
Cincinnati Planer Company	Cincinnati
Cogsdill Manufacturing Company	Detroit
Colonial Steel Company	Pittsburgh
Colonial Tool Company	Detroit
Columbia Tool Steel Company	Chicago Heights, Ill.
Consolidated Concrete Machinery Company	Cincinnati
Cooper Hewitt Company	Hoboken, N. J.
Costello Engineering Company	Pittsburgh
Craine Schrage Steel Company	Detroit
Crucible Steel Company of America	New York City
Cyclops Steel Company	Titusville, Pa.
Cushman Chuck Company	Hartford

D

Danly Machine Specialties Company	Chicago
Darwin & Milner Inc.	Cleveland
Davison Gas Burner & Welding Company, N. C.	Pittsburgh
Dearborn Chemical Company	Chicago
Detroit Seamless Steel Tubes Company	Detroit
Detroit Sheet Metal Works	Detroit
Disston & Sons, Inc., Henry	Philadelphia
Donner Steel Company	Buffalo
Driver-Harris Company	Harrison, N. J.
Dunham Company, Keith	Chicago
Duriron Company Inc., The	Dayton, O.

E

Eastman Kodak Company	Rochester, N. Y.
Eclipse Fuel Engineering Company	Rockford, Ill.
Eclipse Interchangeable Counterbore Company	Detroit
Edlund Machine Company	Cortland, N. Y.
Electric Arc Cutting & Welding Company	Newark, N. J.
Electric Furnace Company	Salem, O.
Electric Welding Machine Company	Detroit
Electro Alloys Company	Elyria, O.
Electro Refractories Corporation	Buffalo
Elkon Works, Inc.	Weehawken, N. J.
Emery-Tatnall Company	Philadelphia
Endicott Forging & Manufacturing Co., Inc.	Endicott, N. Y.
Engelhard Inc., Chas.	New York City
Engelsted, K.,	New York City
Erie Foundry Company	Erie, Pa.
Ex-Cell-O Tool & Manufacturing Company	Detroit

F

Fauver Company, J. N.	Detroit
Federal Machine & Welder Company	Detroit
Federal Products Corporation	Detroit
Ferner Company, R. Y.	Washington, D. C.
Ferry Cap & Set Screw Company	Cleveland
Finkl & Sons Company, A.	Chicago
Firth-Sterling Steel Company	McKeesport, Pa.
Ford Company, J. B.	Wyandott, Mich.
Fredericksen Company	Saginaw, Mich.
Fuels and Furnaces	Pittsburgh
Fusion Electric Welding Corp. Affiliated with Chicago Steel & Wire, Chicago	

G

Gairing Tool Company	Detroit
Gaterman Manufacturing Company, W.	Manitowoc, Wis.
Gathmann Engineering Company	Baltimore, Md.
General Alloys Company	Boston
General Electric Company	Schenectady, N. Y.
Gibb Welding Machines Company	Bay City, Mich.
Gilbert & Barker Manufacturing Co.	Springfield, Mass.
Globe Steel Tubing Company	Milwaukee
Goodell-Pratt Company	Greenfield, Mass.
Goddard & Goddard Company	Detroit
Gordon Company, Claud S.	Chicago
Goss and De Leeuw Machine Co.	New Britain, Conn.
Groov-Pin Corp.	Long Island City, N. Y.

H

Hagan Company, George J.	Pittsburgh
Halcomb Steel Company	Syracuse, N. Y
Haskins Company, R. G.	Chicago
Heacock, Walter G.	Cleveland
Heppenstall Forge & Knife Company	Pittsburgh
Hevi Duty Electric Company	Milwaukee
Hill Curtis Company	Kalamazoo, Mich.
Holcroft & Company	Detroit
Hollup Corporation, C. H.	Chicago
Hoskins Manufacturing Company	Detroit
Houghton & Company, E. F.	Philadelphia
Hunter Saw & Machine Company	Pittsburgh
Hutto Engineering Company, Inc.	Detroit

I

Ideal Industrial Machinery Corp.	Cincinnati
Illinois Steel Company	Chicago
Illinois Tool Works	Chicago
International Nickel Company	New York City
Interstate Iron & Steel Company	Chicago
Iron Age Publishing Company	New York City
Iron and Steel World	Pittsburgh

J

Jarvis Company, Chas. L.	Gildersleeve, Conn.
Jessop Steel Company	Washington, Pa.
Jones & Laughlin Steel Corporation	Pittsburgh

K

Keller Mechanical Engineering Co.	Brooklyn, N. Y.
Kelley, Company, J. W.	Cleveland
Kelly Reamer Company	Cleveland
Kemp Manufacturing Company, C. M.	Baltimore
Keystone Lubricating Company	Philadelphia
Kidder Furnace Company	Canton, Ohio
Kinite Corporation	Milwaukee
King Refractories Company, Inc.	Buffalo
Krembs & Company	Chicago

L

La Porte Machine & Tool Company Inc.	La Porte, Ind.
Leeds & Northrup Company	Philadelphia
Leitz, Inc, E.	New York City
Liberty Machine Tool Company	Hamilton, Ohio
Linde Air Products Company	New York City
Ludlum Steel Company	Watervliet, N. Y.

M

Mackintosh-Hemphill Company	Pittsburgh
Macleod Company	Cincinnati
Mahr Manufacturing Company	Minneapolis
Manning, Maxwell & Moore	New York City
McCrosky Tool Corporation	Meadville, Pa.
McGill Metal Company	Valparaiso, Ind.
Merit Oil Equipment Company	Cleveland
Metal & Thermit Corporation	New York City
Metalwood Manufacturing Company	Detroit
Michigan State College	East Lansing, Mich.
Michigan Tool Company	Detroit
Midvale Company, The	Nicetown, Philadelphia
Milburn Co., Alexander	Baltimore
Milwaukee Die Casting Company	Milwaukee
Molybdenum Corporation of America	Pittsburgh
Morse Twist Drill & Machinery Company	New Bedford, Mass.
Motch & Merryweather Machinery Company	Cleveland
Mueller Brass Company	Port Huron, Mich.

N

National Electric Light Association	Chicago
National Machinery Company	Tiffin, Ohio
National Twist Drill & Tool Company	Detroit
Northwestern Manufacturing Company	Milwaukee
Norton Company	Worcester, Mass.
Nuttall Company, R. D.	Pittsburgh

O

Ohio Seamless Tube Company	Shelby, Ohio
Ohio Steel Foundry Company	Lima, Ohio
O. K. Tool Company	Shelton, Conn.
Olsen Testing Machine Company, Tinius	Philadelphia

P

People's Gas Light & Coke Company	Chicago
Page Steel & Wire Company	Bridgeport, Conn.
Park Chemical Company	Detroit

Parker-Kalon Corporation	New York City
Parker Rust Proof Company	Detroit
Pels & Company, Inc., Henry	New York City
Peninsular Steel Company	Detroit
Penton Publishing Company	Cleveland
Pittsburgh Crucible Steel Company	Midland, Pa.
Pittsburgh Instrument & Machine Company	Pittsburgh
Plibrico Jointless Firebrick Company	Chicago
Potter & Johnson Machine Company	Pawtucket, R. I.
Pratt & Whitney	Hartford
Precision Thermometer & Instrument Co.	Philadelphia
Procunier Company, Wm. L.	Chicago
Publishers' Association	Chicago
Pyrometer Instrument Company	New York City
Production Machine Company	Worcester, Mass.

R

Rail Joint Company	New York City
Reeves Pulley Company	Columbus, Ind.
Republic Flow Meters Company	Chicago
Rockwell Company, Stanley P.	Hartford
Rockwell Company, W. S.	New York City
Roeblings Sons Company, John A.	Trenton, N. J.
Roessler & Hasslacher Chemical Company	New York City
Rollway Bearing Company Inc.	Syracuse, N. Y.
Rotor Air Tool Company	Cleveland
Rummins & Murray, Inc.	Detroit

S

Seneca Falls Machine Company	Seneca Falls, N. Y.
Sentry Company	Taunton, Mass.
Shawinigan Products Corporation	New York City
Shenango Penn Mold Company	Dover, O.
Sherr Company, Inc., George	New York City
Shore Instrument & Manufacturing Company	Jamaica, N. Y.
Simonds Saw & Steel Company	Lockport, N. Y.
Skinner Chuck Company	New Britain, Conn.
Sleeper & Hartley, Inc.	Worcester, Mass.
Southern Manganese Steel Company	St. Louis
Spencer Turbine Company	Hartford
Square D Company,	Detroit
Standard Electrical Tool Company	Cincinnati
Standard Fuel Engineering Company	Detroit
Standard Gage Company	Poughkeepsie
Standard Oil Company of Indiana	Chicago
Standard Steel and Bearings Inc.	Plainville, Conn.
Standard Tool Company	Cleveland
Starrett, L. S.,	Athol, Mass.
Steel City Testing Laboratory	Detroit
Steel Publications, Inc.	Pittsburgh
Strand & Company, N. A.	Chicago
Strong, Carlisle & Hammond Company	Cleveland
Stuart & Company, D. A.	Chicago
Sullivan Machinery Company	Chicago
Surface Combustion Company	New York City
Swedish Charcoal Steels, Inc.	New York City
Swedish Crucible Steel Company	Detroit

T

Tate-Jones & Company Inc.	Leetsdale, Pa.
Taylor Instrument Companies	Rochester, N. Y.
Taylor Sons Co., Chas.	Cincinnati
Taylor-Winfield Corporation	Warren, O.
Torchweld Equipment Company	Chicago
Thomson and Sons, Henry G.	New Haven, Conn.
Timken Roller Bearing Company	Canton, Ohio
Thomson Electric Welding Company	Lynn, Mass.
Tomkins-Johnson Company	Jackson, Mich.
Transue & Williams Steel Forging	Alliance, Ohio
Trent Company, Harold E.	Philadelphia
Tuffley Burner Corporation	Syracuse, N. Y.
Tuthill Pump Company	Chicago

U

Una Welding & Bonding Company	Cleveland
Union Drawn Steel Company	Beaver Falls, Pa.
Unishear Company	New York City
Universal Steel Company	Bridgeville, Pa.
University of Michigan	Ann Arbor, Mich.
U S L Battery Corp.	Niagara Falls, N. Y.

V

Vanadium Alloys Steel Company	Latrobe, Pa.
Victor Peninsular Company	Detroit
Vulcan Crucible Steel Company	Aliquippa, Pa.
V & O Press Company	Hudson, N. Y.

W

Wall Brothers Company	Detroit
Waterbury Farrel Foundry & Machine Co.	Waterbury, Conn.
Wave Cut File & Tool Corporation	New York City
Wiegand Company, Edwin L.	Pittsburgh
Welding Engineer	Chicago
Weldit Acetylene Company	Detroit
West and Dodge Thread Gage Company	Boston
Westinghouse Electric & Mfg Company	East Pittsburgh
Wetmore Reamer Company	Milwaukee
Wheelock, Lovejoy & Company, Inc.	Boston
Whitman-Barnes-Detroit Corporation	Detroit
Whitney Manufacturing Company	Hartford
Whitney Metal Tool Company	Rockford, Ill.
Wickwire Spencer Steel Company	Buffalo
Williams & Company, J. H.	Buffalo
Wilson-Maeulen Company	New York City
Witherow Steel Company	Pittsburgh

Y

Young Brothers Company	Detroit

Z

Ziv Steel & Wire Company	Chicago

Leetsdale, Pa.
Rochester, N. Y.
Cincinnati
Warren, O.
Chicago
New Haven, Conn.
Canton, Ohio
Lynn, Mass.
Jackson, Mich.
Alliance, Ohio
Philadelphia
Syracuse, N. Y.
Chicago

Cleveland
Beaver Falls, Pa.
New York City
Bridgeville, Pa.
Ann Arbor, Mich.
agara Falls, N. Y.

Latrobe, Pa.
Detroit
Aliquippa, Pa.
Hudson, N. Y.

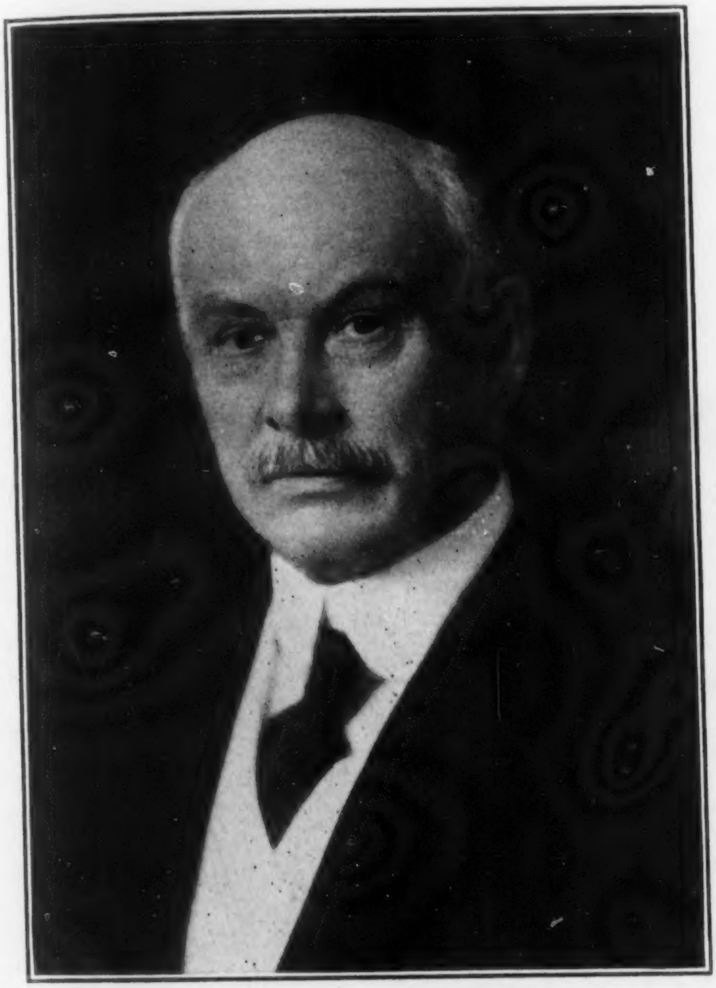
Detroit
Waterbury, Conn.
New York City
Pittsburgh
Chicago
Detroit
Boston
East Pittsburgh
Milwaukee
Boston
Detroit
Hartford
Rockford, Ill.
Buffalo
Buffalo
New York City
Pittsburgh

Detroit

Chicago

HONORARY MEMBER OF THE SOCIETY DIES

IT is with regret that we learn of the death of Judge Elbert H. Gary, honorary member of the American Society for Steel Treating, having been elected to that position in 1926 at the Chicago Convention. For



Judge Elbert H. Gary

more than twenty-six years he has been one of the greatest figures in American industrial life, and his influence as member of the society has been most helpful.

Elbert H. Gary was born near Wheaton, Illinois, October 8, 1846. He attended Wheaton College and the University of Chicago, receiving the degree of LL. B. In 1882 he was admitted to the bar of the United States supreme court, and in 1887, he, with several others, formed the Federal Steel Company, abandoning his law practice to enter the steel business. The record of his achievements in the iron and steel world are well known to all and his death means a distinct loss to mankind.

News of the Chapters

STANDING OF THE CHAPTERS

DURING the month of July there were 67 new and reinstated members, while 189 were lost through arrears, resignations, and deaths, leaving a net loss for the month of 132 members. This is the first month in two years when the Society has not shown a gain in membership. The total membership of the Society on August 1 was 4,665.

In the following tabulation there appears the relative membership standing of the 32 chapters and 3 groups of the Society as of August 1, 1927.

GROUP I		GROUP II		GROUP III	
1. Detroit	483	1. Hartford	127	1. Tri-City	79
2. Chicago	404	2. Milwaukee	123	2. New Haven	78
3. Philadelphia	340	3. Dayton	123	3. Los Angeles	75
4. Pittsburgh	340	4. Lehigh Valley	117	4. Washington	66
5. Cleveland	317	5. Canton-Mass.	108	5. Worcester	65
6. New York	274	6. Golden Gate	103	6. Southern Tier	63
7. Boston	250	7. Cincinnati	95	7. Rochester	61
		8. Indianapolis	92	8. Toronto	59
		9. Syracuse	88	9. Rockford	56
		10. St. Louis	83	10. Columbus	56
		11. Montreal	71	11. Providence	54
		12. Buffalo	60	12. Schenectady	44
		13. North-West	52	13. Fort Wayne	36
				14. Springfield	32
				15. Notre Dame	24

The following chapters suffered the heaviest losses of members being dropped for non-payment of dues: Boston 6; Chicago 15; Cleveland 14; Detroit 17; Fort Wayne 7; Golden Gate 6; Hartford 7; Lehigh Valley 9; Los Angeles 6; Montreal 20; New York 7; Philadelphia 19; Pittsburgh 7; Rockford 10.

GROUP I—The position of the chapters in this group is the same as in the last report. However, all of the chapters suffered a loss of membership, the heaviest being Philadelphia with 17; Cleveland next with 10, and Detroit and Boston with 3 each.

GROUP II—All of the chapters in this group with the exception of the new Dayton chapter and Canton-Massillon group suffered a loss. Dayton with a net gain of 6 advanced from 4th to 3rd place, displacing Lehigh Valley. Canton-Massillon with a net gain of 3 advanced from 6th to 5th position, displacing Golden Gate. Montreal with a loss of 19 went from 10th to 11th place.

GROUP III—Los Angeles with a loss of 5 went from 1st place to 3rd, giving honor to Tri City. Southern Tier with a loss of 5 went from 5th to 6th place, while Rochester with a gain of 2 advanced from 9th position to 7th. Rockford with a loss of 9 changed its position from 7th to No. 9.

reinstated members,
and deaths, leaving
first month in two
bership. The total

membership standing
ust 1, 1927.

GROUP III

Tri-City	79
New Haven	78
Los Angeles	75
Washington	66
Worcester	65
Southern Tier	63
Rochester	61
Toronto	59
Rockford	56
Columbus	56
Providence	54
Schenectady	44
Fort Wayne	36
Springfield	32
Notre Dame	24

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to No. 9.